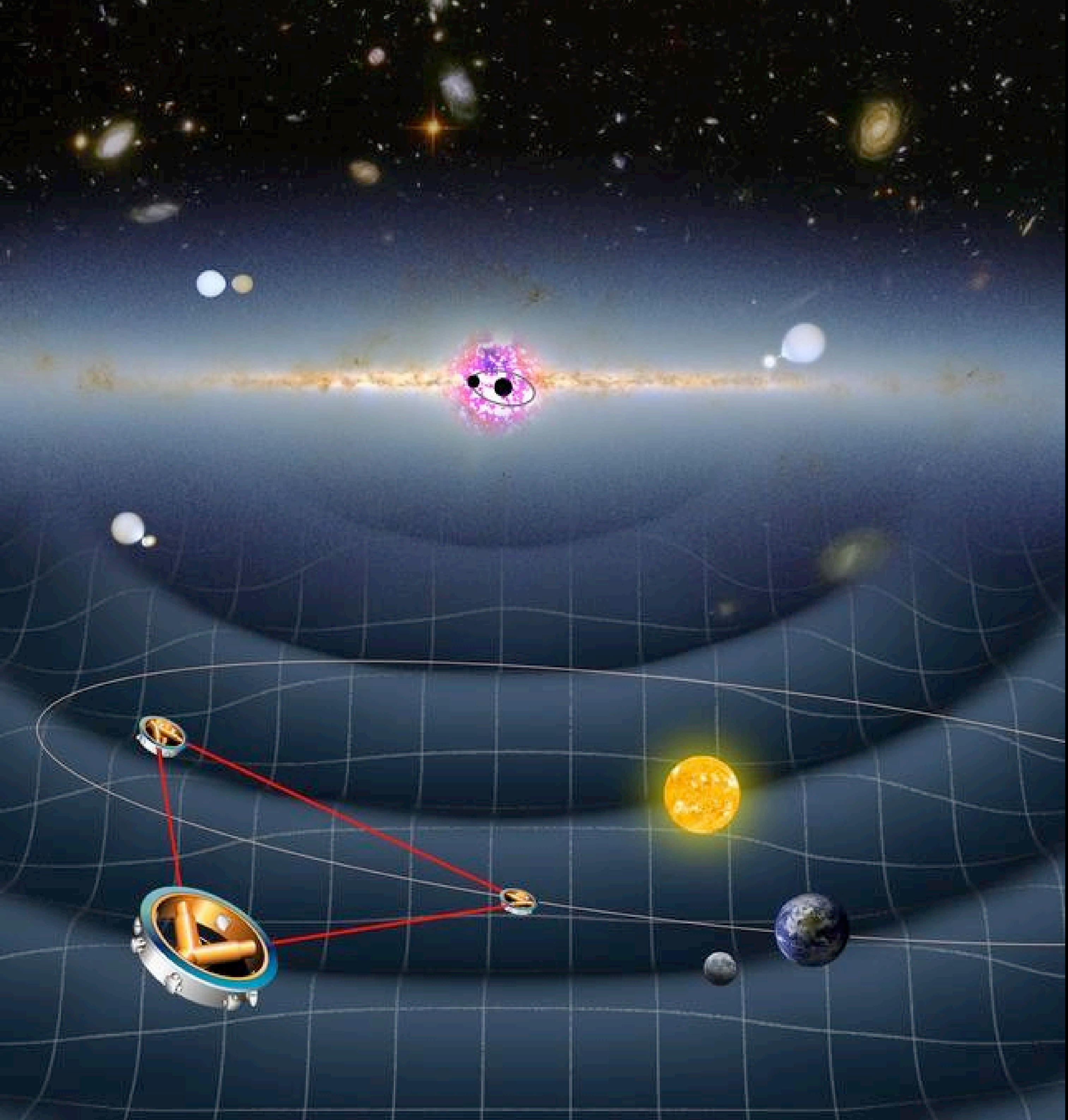


LISA Science

Sterl Phinney

Caltech

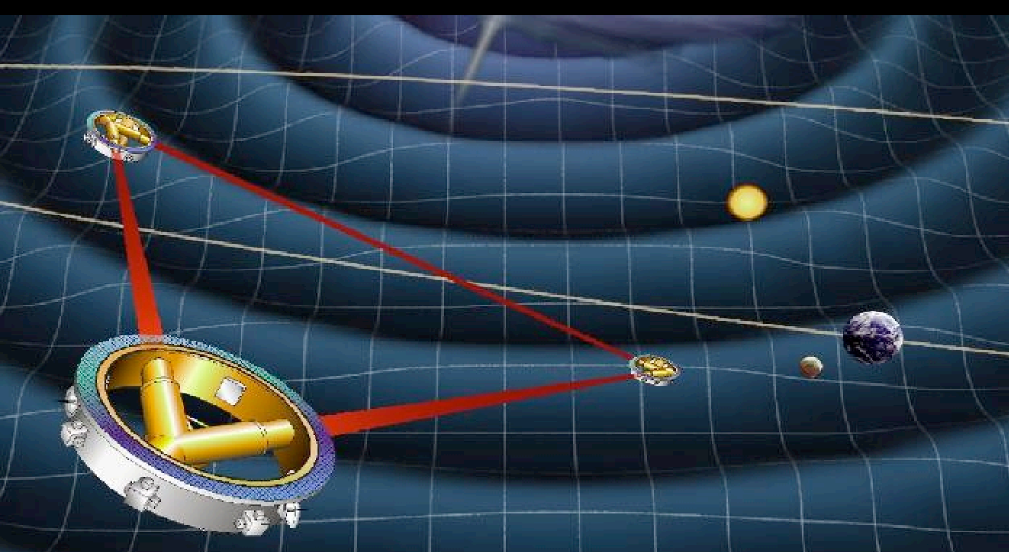
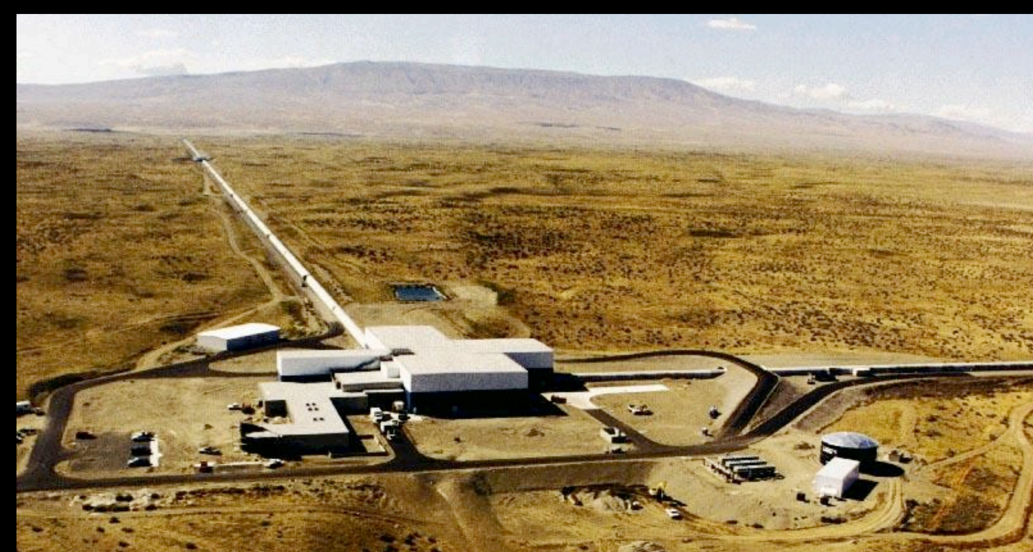
For hunting in the dark,

For hunting in the dark, big eyes are good

For hunting in the dark, big eyes are good

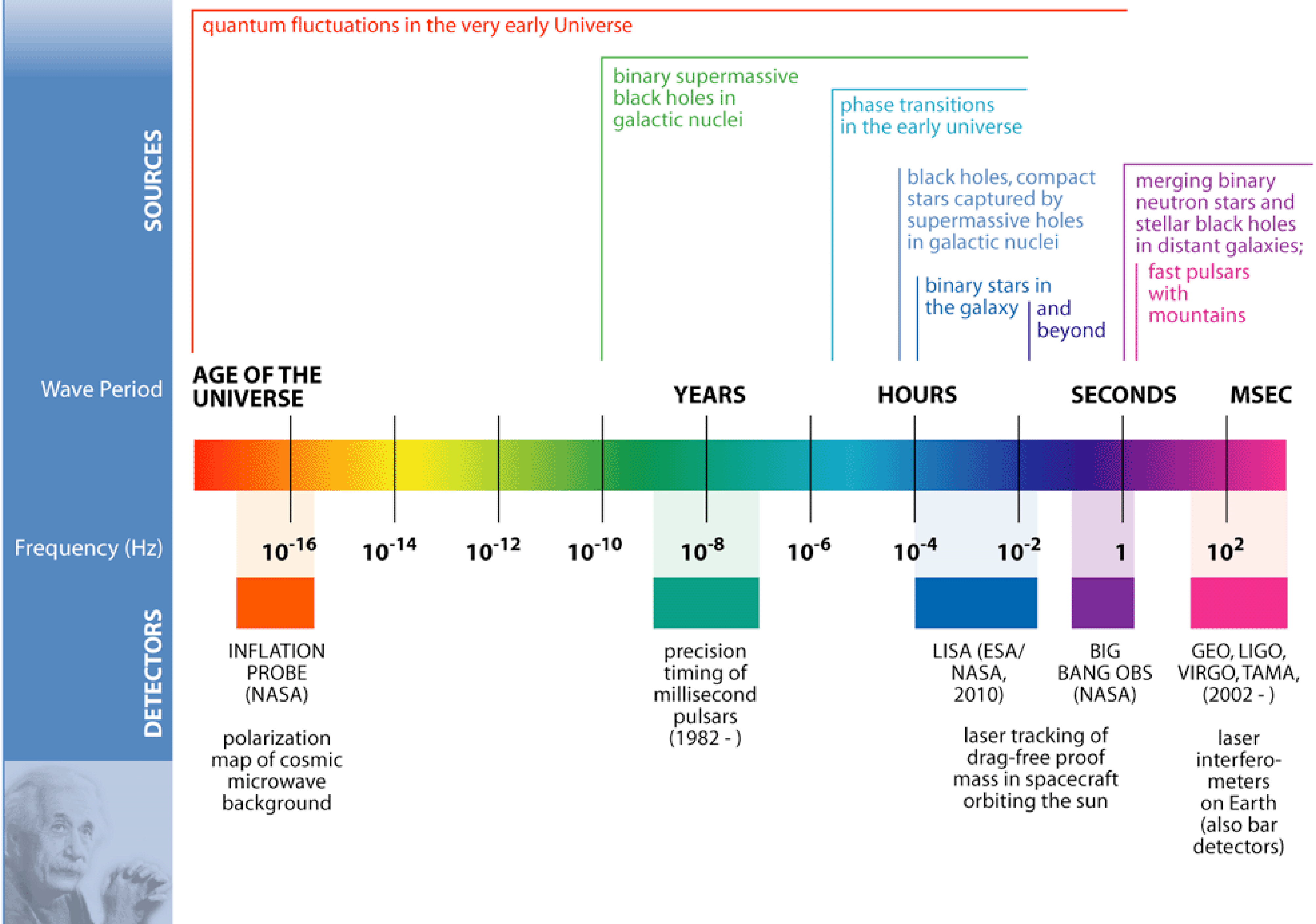


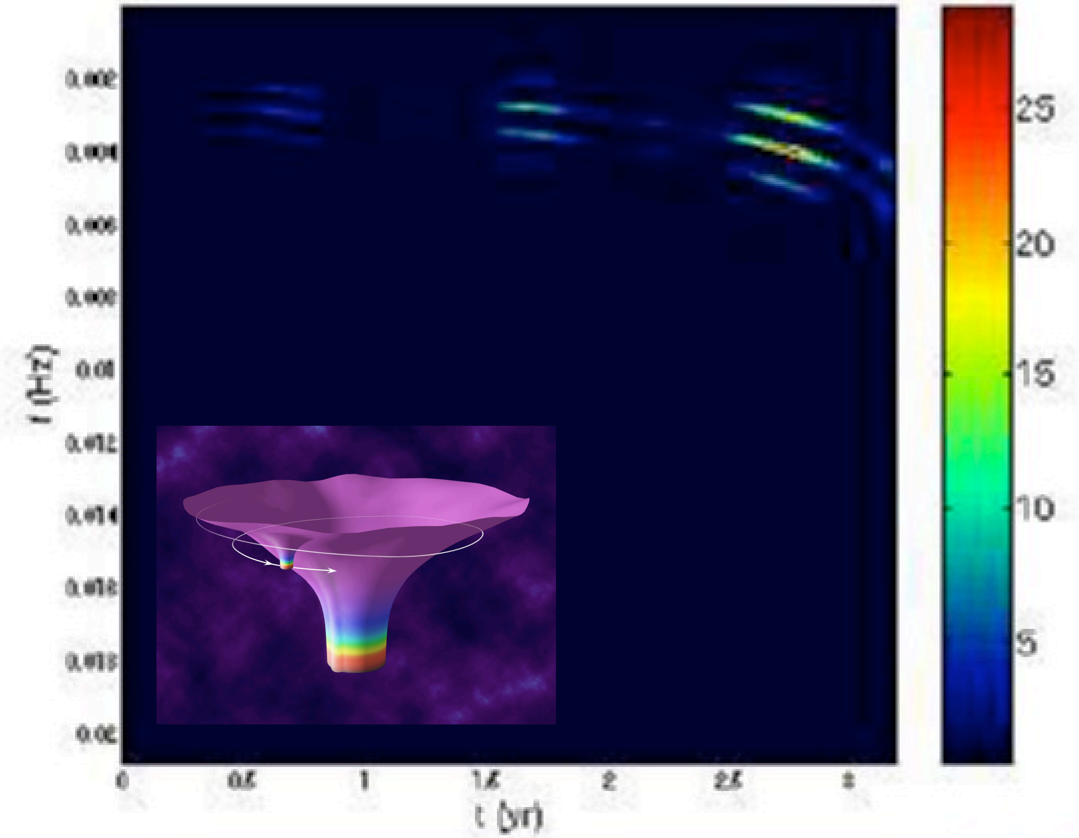

But to be *really* successful, you need vibration sensors.

- black holes
- dark stellar remnants
- dark matter
- dark energy
- black strings
- ....

THE GRAVITATIONAL WAVE SPECTRUM



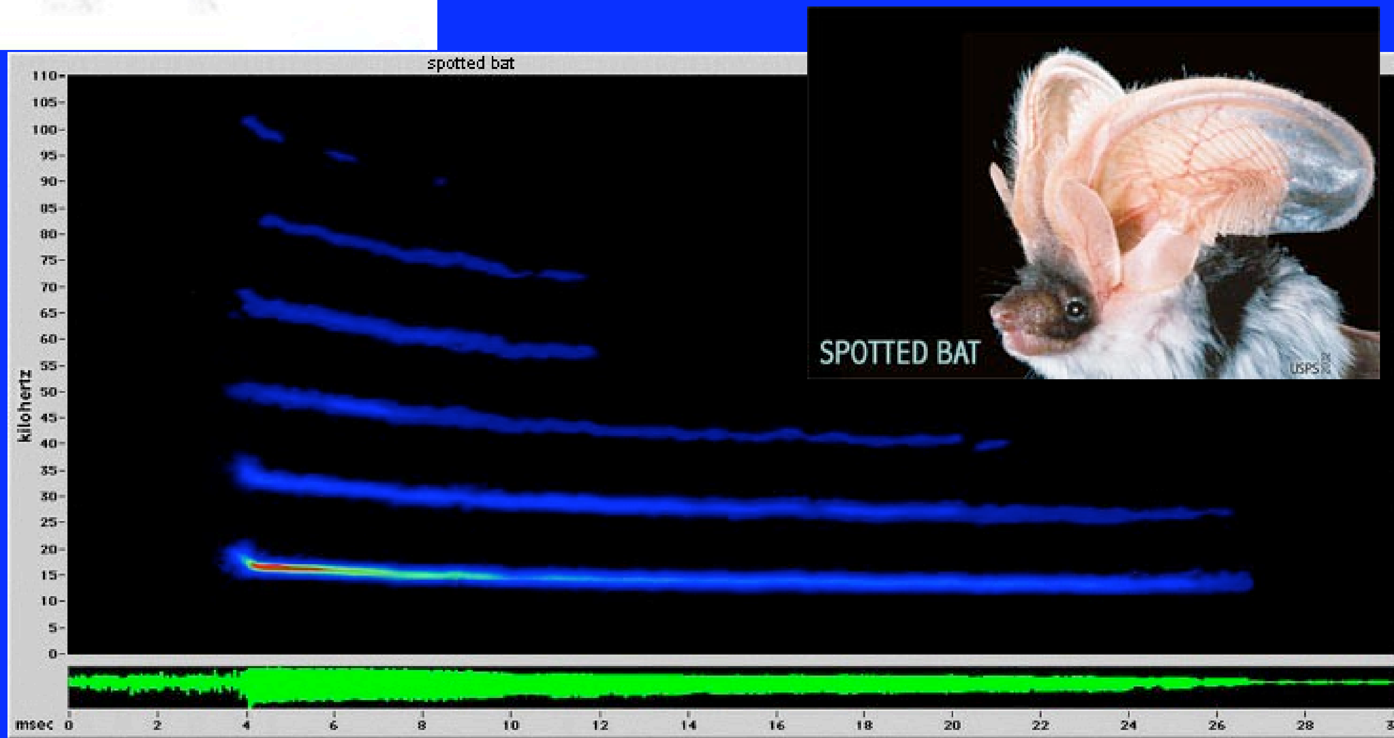


Species identification and census-taking by Sonogram (time-frequency maps).

EMRI, $10/10^6$, $e=0.4$

$a/M=0.8$, $i=45$, $r_{p0}=11M$

Male spotted bat



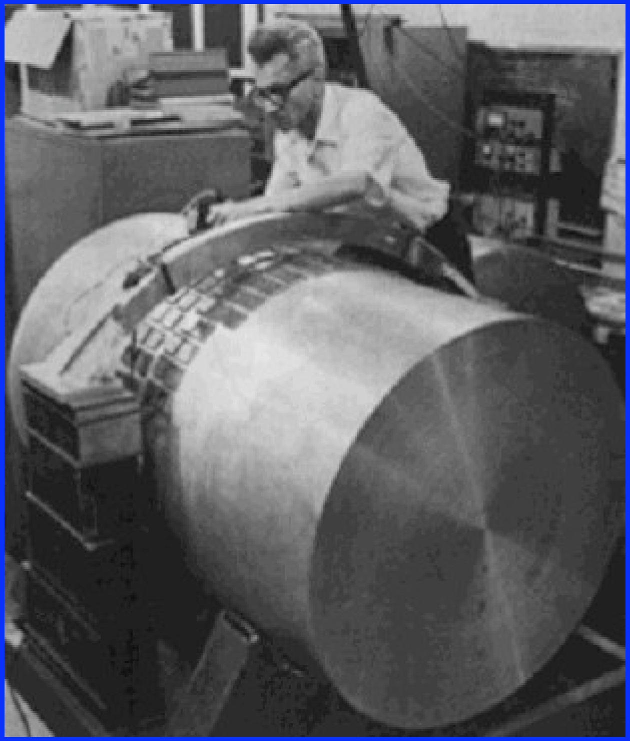
THE OLD EARS

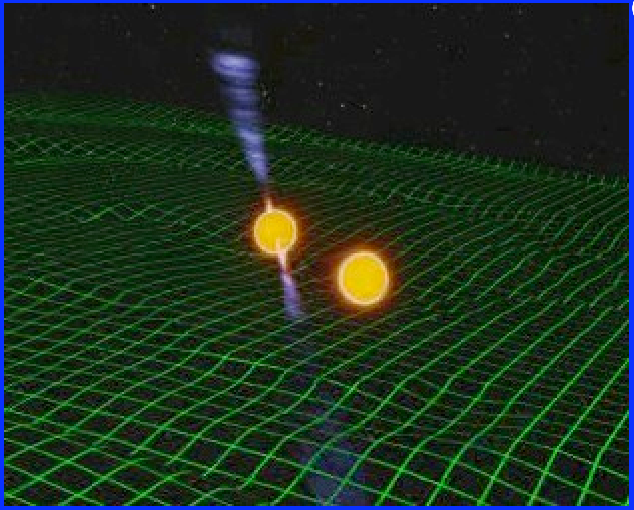
1966 — 1986 — 2006

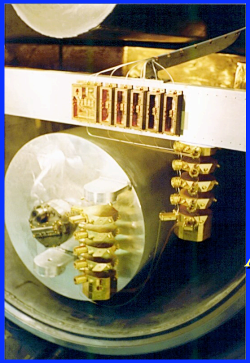
Weber bar

msec pulsar timing network

cryogenic bars







ALLEGRO

AURIGA

THE NEW EARS

2005 — 2015 — 2025+

LIGO & GEO600 S5 (1yr) run

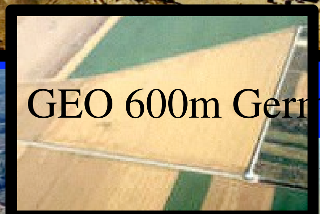
VIRGO

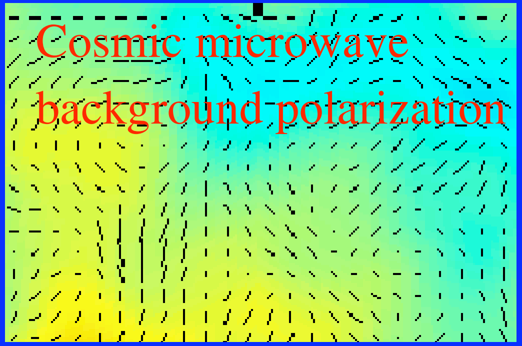
Adv. LIGO

LISA

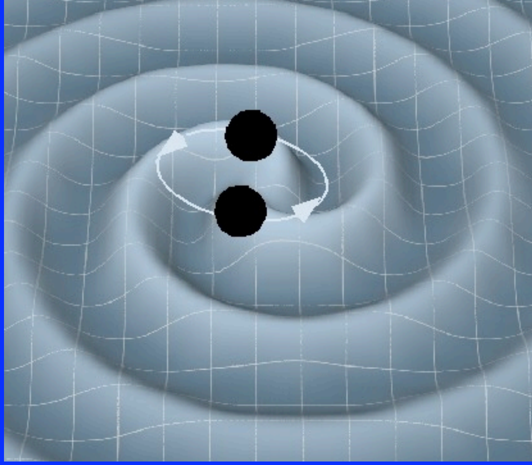
CMBPol?

BBO?





Gravitational waves: [Einstein, 1916]



Propagating transverse distortions of spacetime.

Produced by accelerating masses.

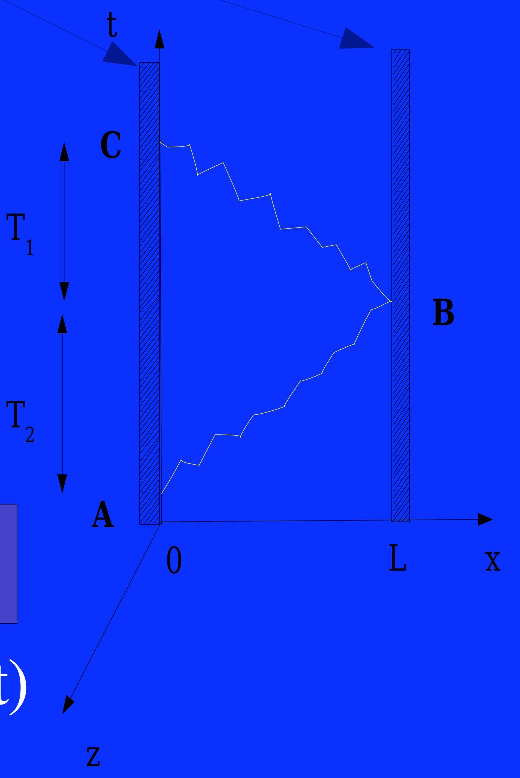
Bounce light between two freely falling mirrors
[Bondi 1957]

Use “Lagrangian” coordinates, mirrors at x=0, x=L. Light follows null geodesic in the wave-distorted spacetime:

$$0 = ds^2 = -c^2\, dt^2 + [1 + h(t)]\, dx^2$$

gravitational wave

$h(t) \equiv h_+(t - z/c)$

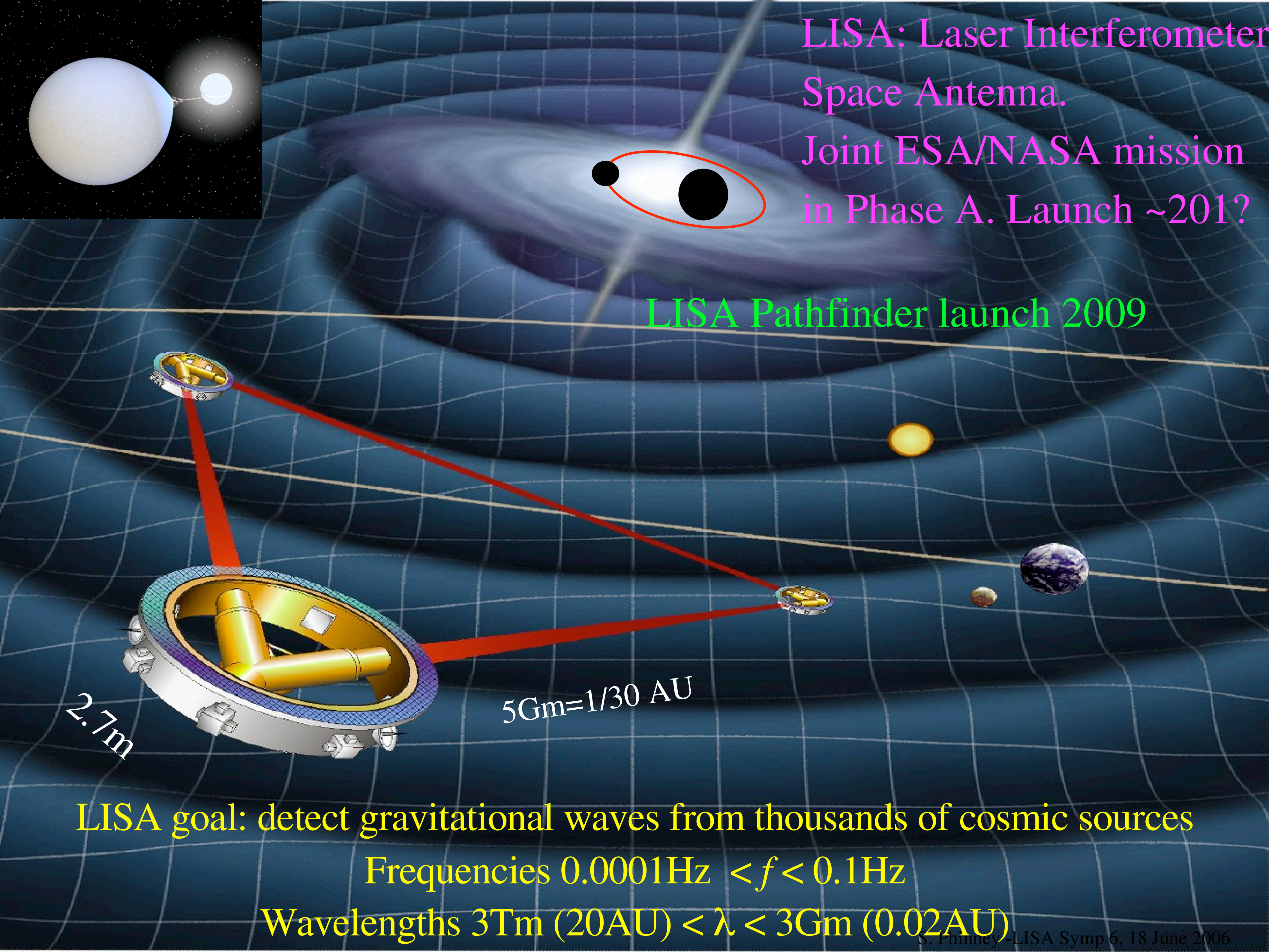


Coordinate velocity of photons

$$v = \frac{dx}{dt} = \frac{c}{\sqrt{1 + h(t)}}$$

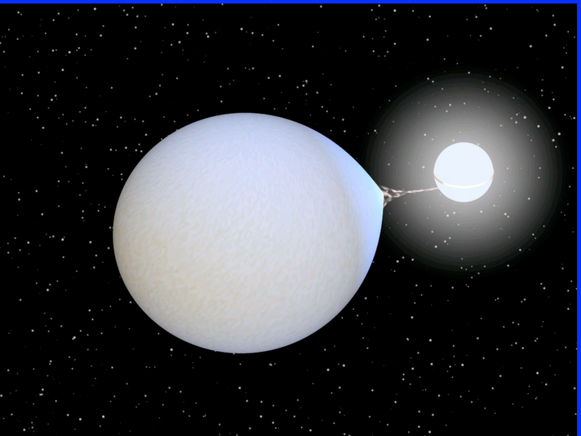
(h_x produces no effect)

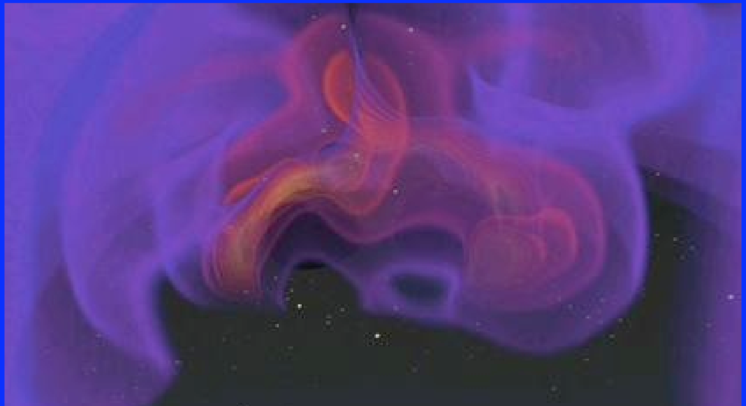
$$t_C - t_A = \int \frac{dx}{v} \approx \frac{1}{c} \int [1 + h(t, x)/2]\, dx$$

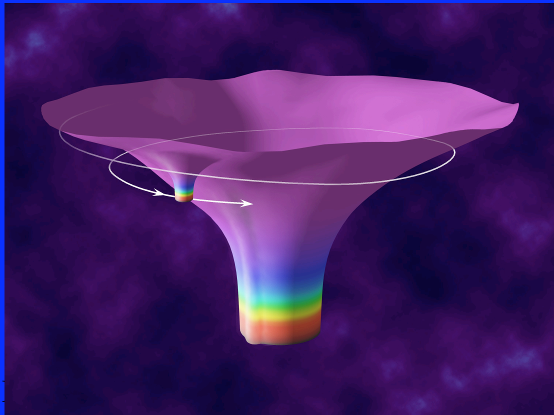

LISA: Laser Interferometer
Space Antenna.
Joint ESA/NASA mission
in Phase A. Launch ~201?
LISA Pathfinder launch 2009
2.7m
5Gm=1/30 AU
LISA goal: detect gravitational waves from thousands of cosmic sources
Frequencies 0.0001Hz $< f <$ 0.1Hz
Wavelengths 3Tm (20AU) $< \lambda <$ 3Gm (0.02AU)
S. Phinney -LISA Symp 6, 18 June 2006

LISA sources

- Supermassive and intermediate mass black hole binaries merging. ~10, signal detected for ~year
- Galactic white dwarf binaries (double degenerates and AM Cvns) ~10,000, signal constant for >> mission life
- Compact objects spiralling into supermassive black holes in galactic nuclei ~100, signal detected for ~year.
- Burst sources (e.g. from cosmic string cusps and kinks)
- Cosmological backgrounds (e.g. from electroweak phase transition, strings, dimensionality transitions)







S.

Emphasis: LISA's unique role

1) Precision measurement of (fairly) simple systems that are theoretically tractable. LISA measures interesting parameters and sources that are inaccessible to electromagnetic measurements.

2) Astronomers' greatest interest is in sources for which there are also electromagnetic diagnostics, so both sets of measurements can supply information on interdependent aspects of sources that cannot be obtained with GW or EM measurement alone.

3) Discovery space: the known unknowns and the unknown unknowns. Possibly the greatest impact...

1) Precision measurement of (fairly) simple systems that are theoretically tractable. LISA measures interesting parameters and sources that are inaccessible to electromagnetic measurements.

1) Static and dynamic properties of black hole spacetimes
2) Spins and mergers history of black holes in galactic nuclei
3) Confirmation? of intermediate-mass black holes
4) Mass fraction and mass segregation of stellar remnants in stellar cusps in galactic nuclei.

2) Astronomers' greatest interest is in sources for which there are also electromagnetic diagnostics, so both sets of measurements can supply information on interdependent aspects of sources that cannot be obtained with GW or EM measurement alone.

1) Accreting white dwarfs

2) Tidally heated white dwarfs

3) White dwarf mergers/transient events

4) black hole mass & spin in accretion disk with radius-frequency, radius-thermal time (post-merger SMBH) or radius-viscous time (embedded EMRIs) maps.

5) Combined tidal-disruption/gravitational wave events

6) EMR bursts from Milky Way black hole

7) Cosmography with electromagnetic z and gravitational D_L(z).

3) Discovery space: the known unknowns and the unknown unknowns. Possibly the greatest impact....

1) cosmic superstrings

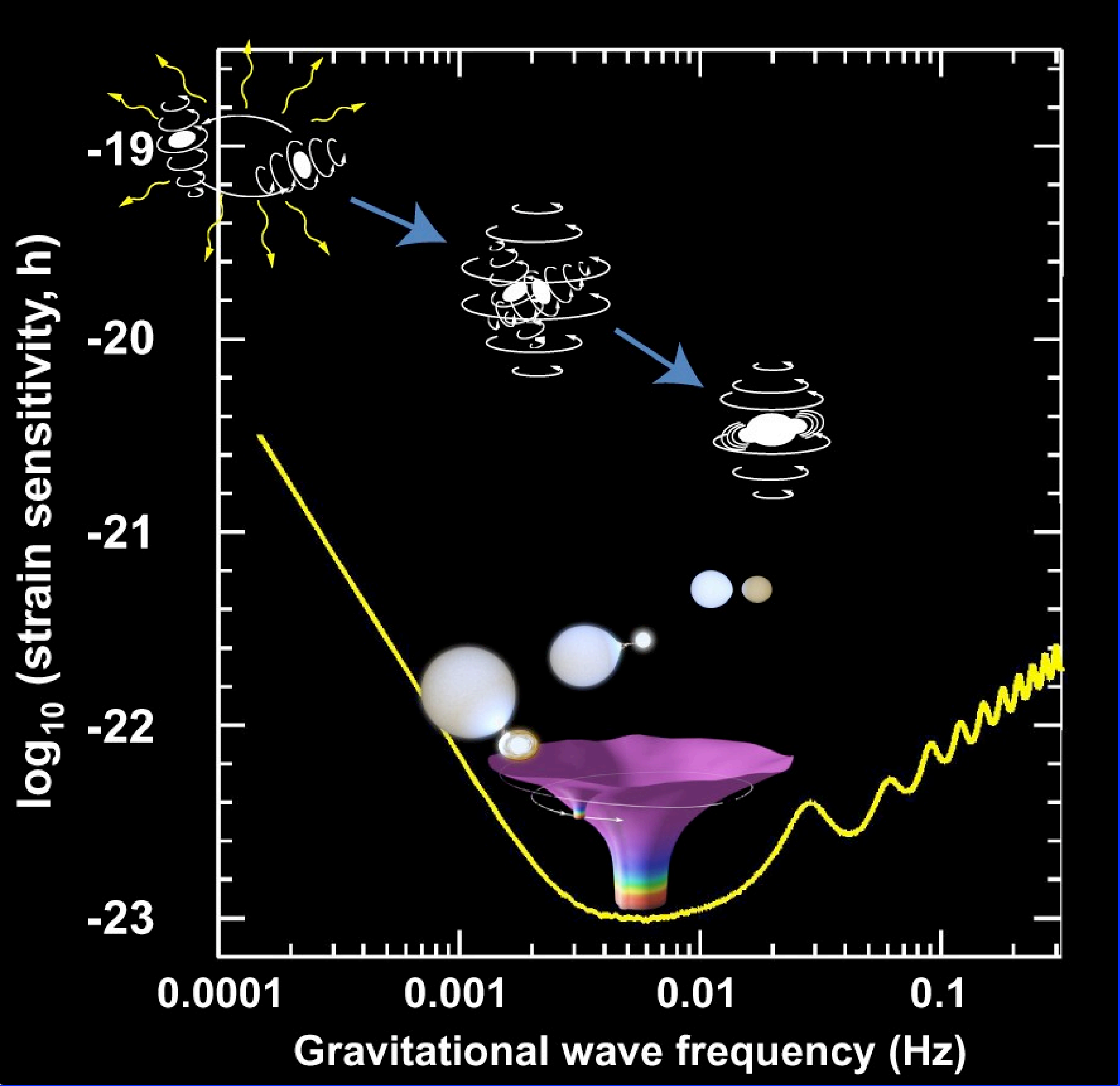
2) a background (electroweak, dimensionality, astrophysical)

3) Unexpected astrophysical sources

4) black holes aren't black holes, or GR has macroscopic quantum corrections (“fuzz balls”).

5) science fiction isn't fiction (wormholes...)

6) ???



LISA sources and sensitivity

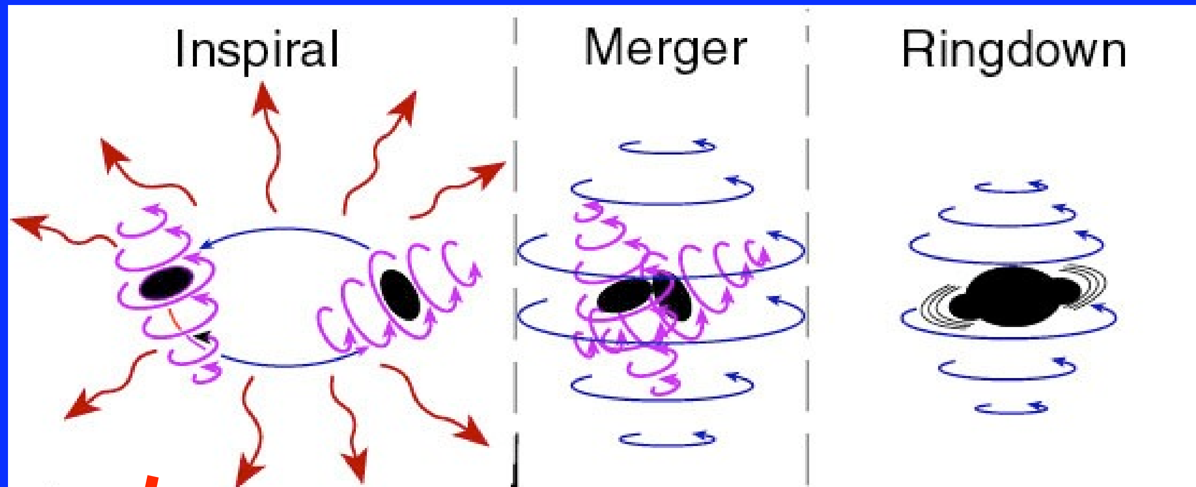
(1y sky average at S/N=5)

10^6+3x10^5 Msun
black hole binary at z=1.
40 days at f>0.0001Hz
S/N=2500

White dwarfs at 1kpc,
P=33, 10, 3.3 min
>10^6 years in band!
S/N=6, 80, 210

1 + 10^6 Msun EMRI
at z=0.2
5 years in band
S/N=30

Merging supermassive black holes



Post-Newtonian. Consider 10^6+10^6 Msun at z=1, drawn to scale:

0.00002Hz, SNR=5, t=2yr, 700 orbits, 20 L-S precessions to go

0.00003Hz, t=1yr, SNR=16

0.00001Hz, t=13d, SNR=65

0.0003Hz, t=1 d, SNR=120

Merger Rate(s) of Supermassive Black holes

Mainly gas accretion. >10^6 Msun seeds in large low z fragments: avoid Supereddington, recoil:

LISA merger rate ~1/y, z<5, 10^6-10^7 Msun.

Haehnelt 1997

Kauffman & Haehnelt 2000

Mainly mergers. <10^4 Msun seeds in small high-z fragments

LISA merger rate ~300/y, z~20, 10^4-10^5 Msun. A Nuisance!

Wyithe & Loeb 2003

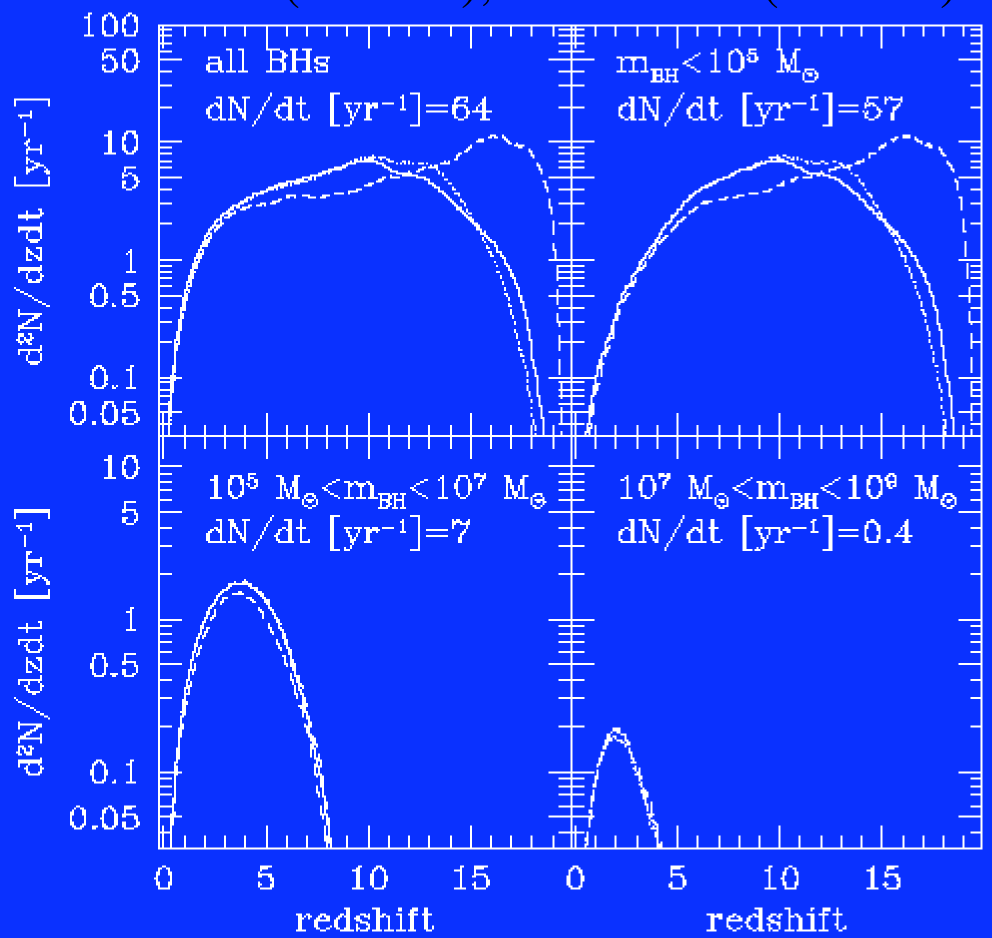
Volonteri et al 2003

Menou & Haiman 2004

Rare seeds and ejections from small galaxies:

LISA merger rate ~30/y, z~3-10

In 3yr, LISA see 192 SMBH (SNR>1), 55 sources (SNR>5)



Sesana et al 2005.

If GR is correct, binary black hole waveforms are a 17 parameter family:

- D distance
- $\hat{n}$ direction to source (2 sky angles)
- M_1, M_2, S_1, S_2 masses, spins
- $\hat{S}_1(t_0), \hat{S}_2(t_0)$ directions of spins
- $\hat{L}(t_0)$ direction of orbit normal: i, PA
- $a(t_0)$, semimajor axis
- $e(t_0)$, eccentricity
- $\gamma(t_0)$, longitude of periastron
- $\Phi(t_0)$, mean anomaly

- More parameters if non-Kerr or not GR.
- If $M_2 \ll M_1$ (EMRI), can drop S_2, $\hat{S}_2$, so EMRIs are 14 parameter family.

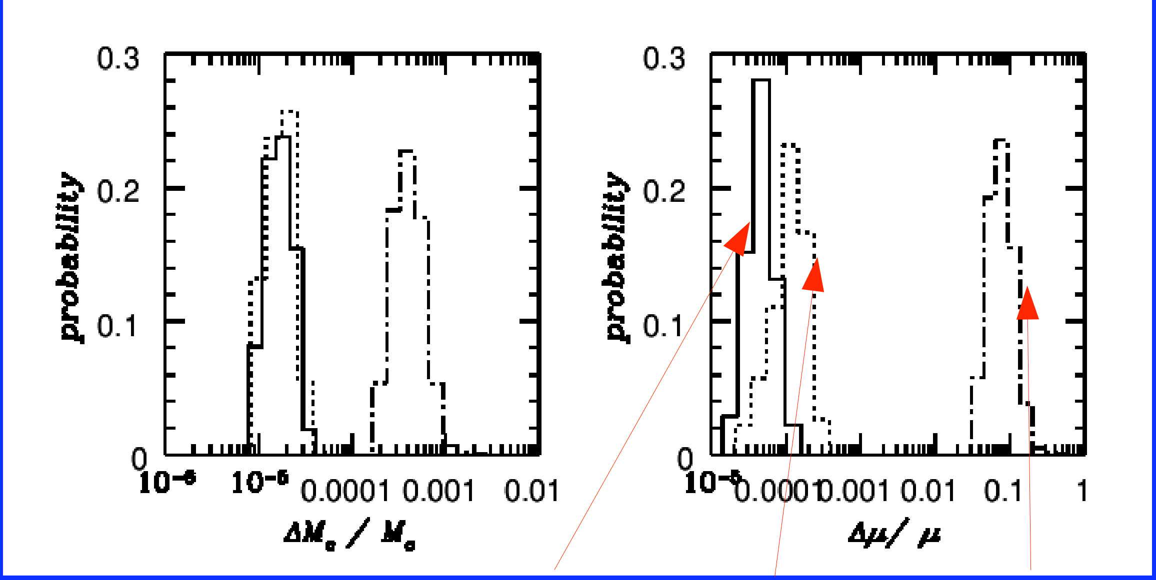
Accuracy of BBH Parameter determination

- sky position depends on:
  - early (postNewtonian) phase.
  - SNR at end of merger (dominated by end)
- Need both!
- fractional error in
  - masses ~10^{-4}
  - spins, spin angles ~10^{-3}
  - distance ~$10^{-2}/5$
  - sky position ~$10^{-3}/5$ sr
- C. Cutler, Phys. Rev. D 57, 7089 (1998). [phase only]
- S. Hughes, MNRAS 331, 805 (2002). [phase only]
- A. Vecchio, astro-ph/0304051 (2004). Hughes & Lang 2006 [phase and amplitude]

Precision cosmography (cf JDEM). Limited by weak lensing modulation of D(z)! (~1%). Need EM signal for z

Shown: 10^6+10^6 at z=1

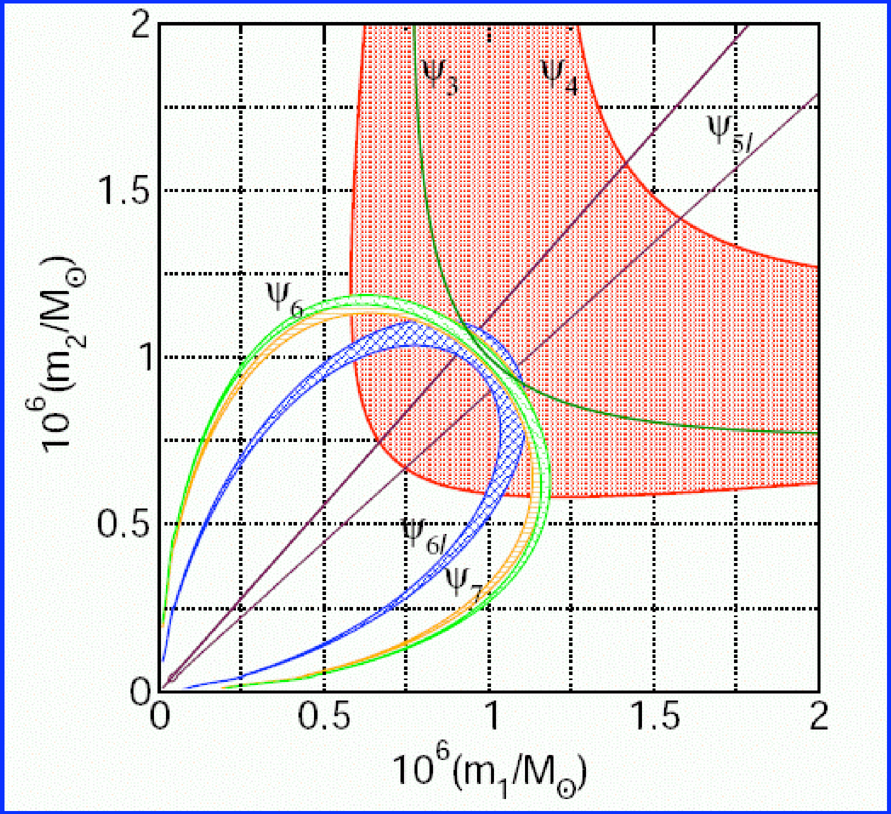
Spinning BH: Spin-orbit coupling removes degeneracy between position and inclination, increases accuracy of D,position x5



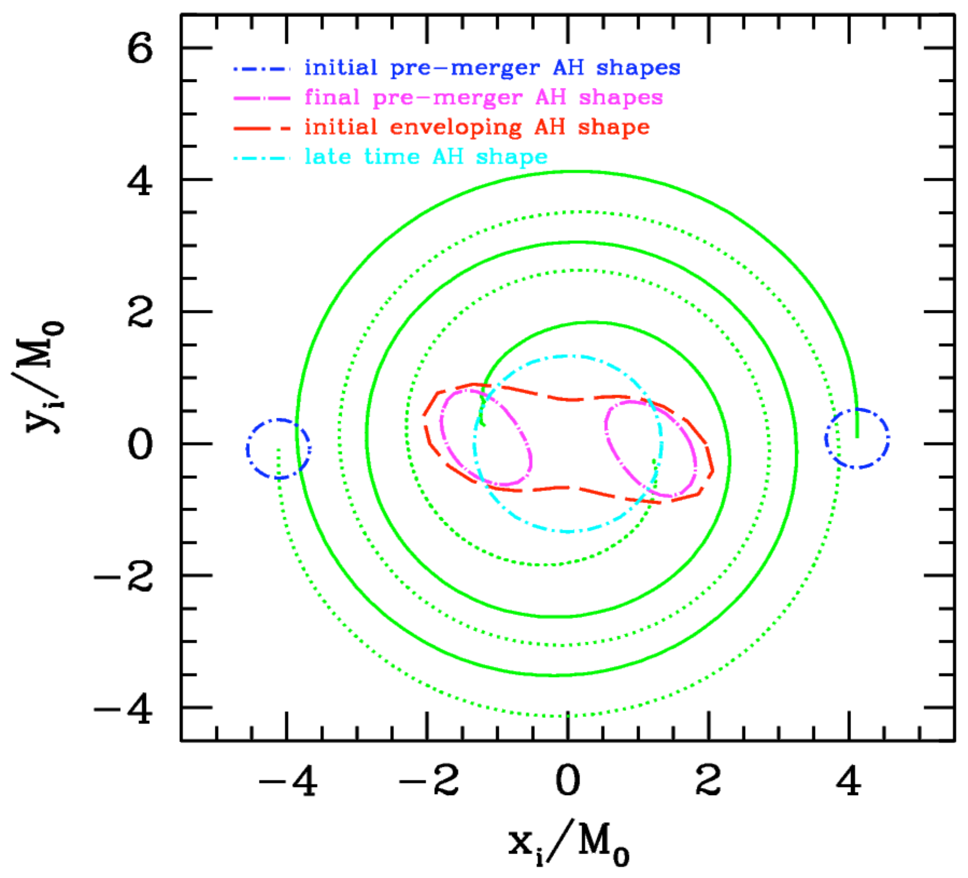
a/M= 0.9 0.5 0

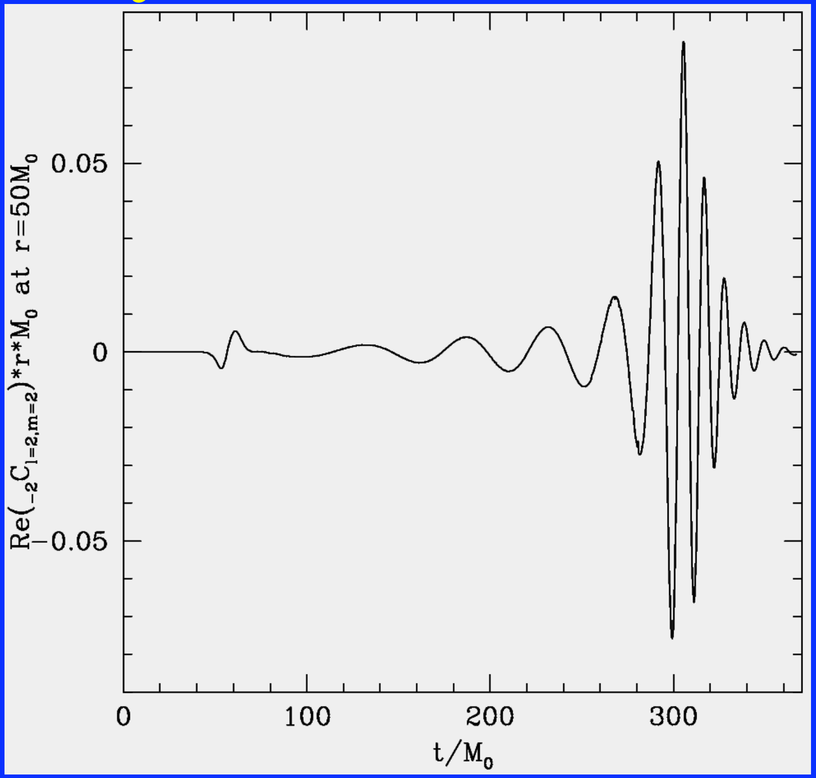
Testing nonlinear GR with inspirals

- 10^6+10^6 Msun at z=1 observed with LISA will measure all 9 3.5PN $(v/c)^7$ post-Newtonian coeffs, including nonlinear tails (waves scattering on spacetime curvature and each other)
- For non-spinning black holes, these depend only on 2 masses -highly overdetermined
- Covariances of parameters mean best tests use combinations, not just fit values. Advanced LIGO 2.5PN 100%, LISA 3.5PN, 10%
- Arun et al gr-qc/0604067



Testing GR/black hole hypothesis with numerical relativity





Initial coordinate (proper) separation: 7.4M (9.8M)

Final BH angular momentum:

J=0.70 ± 0.02 M²

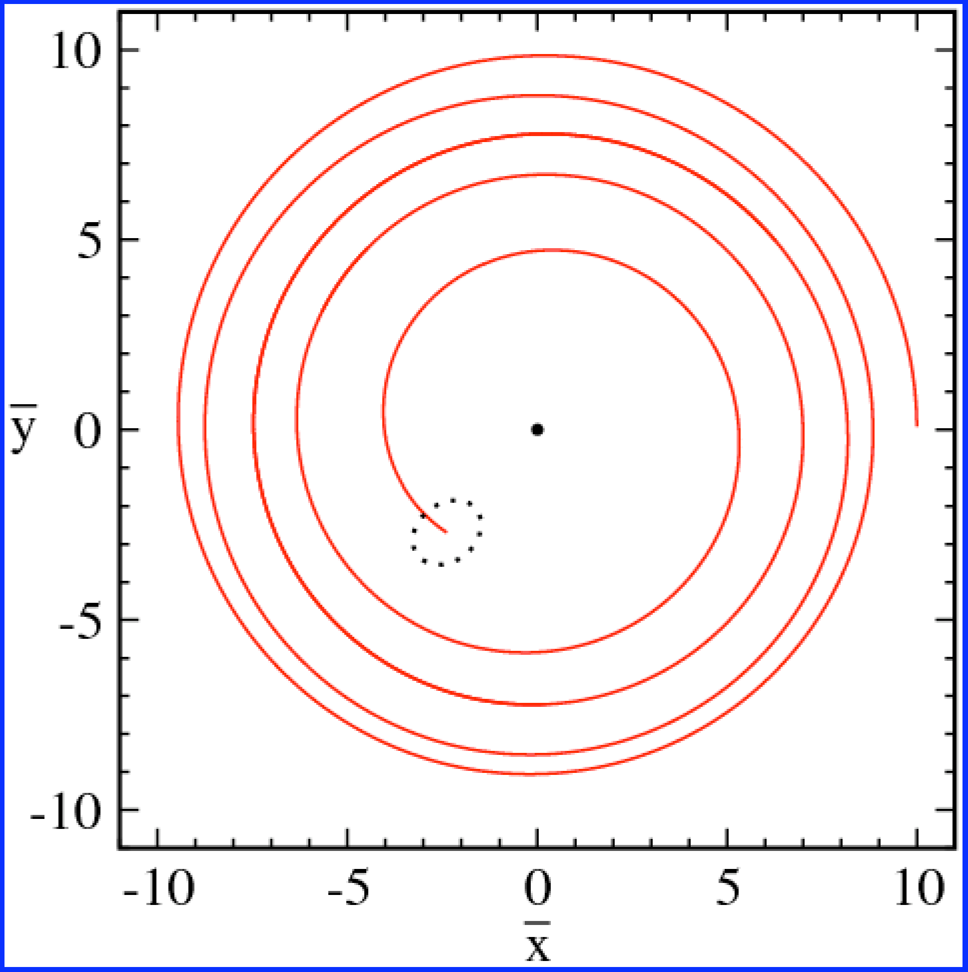
Energy radiated:

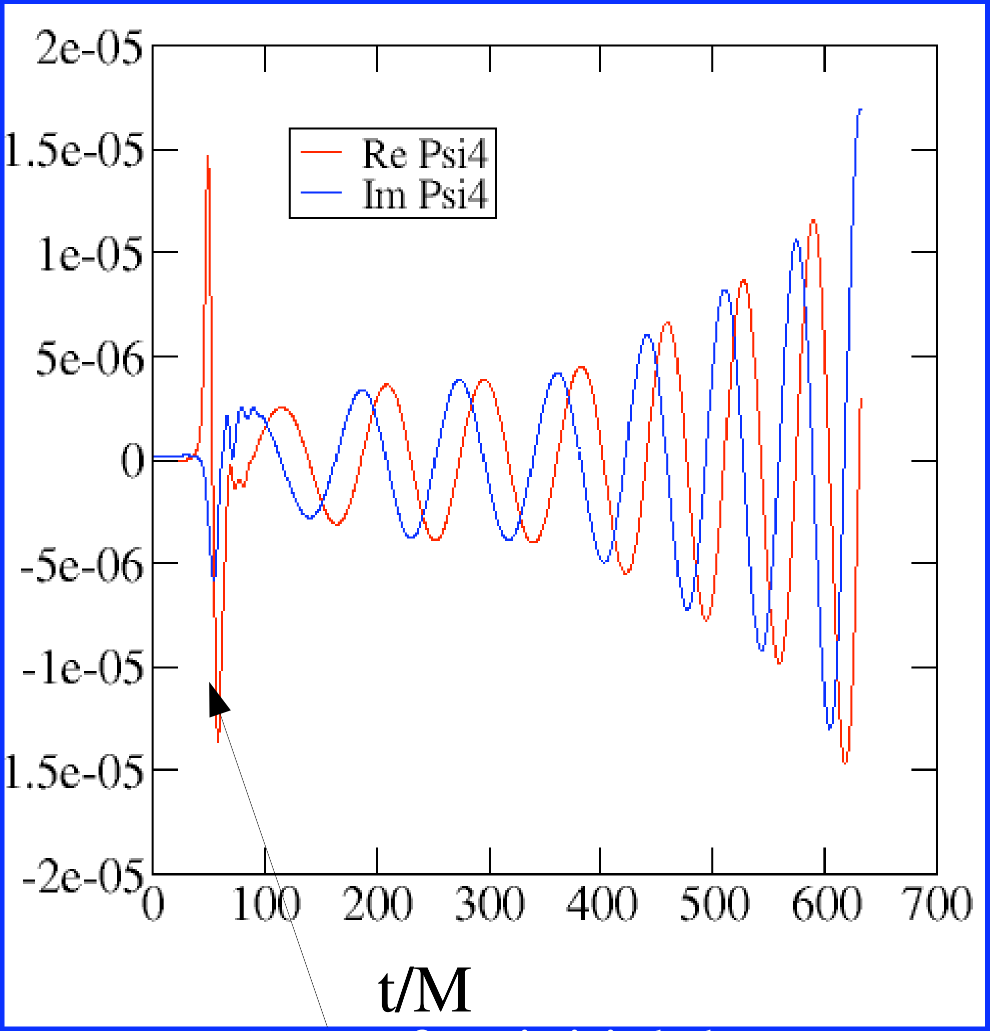
0.043M ± 0.004M

MOVIE TIME

F. Pretorius 2005. Adaptive mesh

Testing GR/black hole hypothesis with numerical relativity of mergers

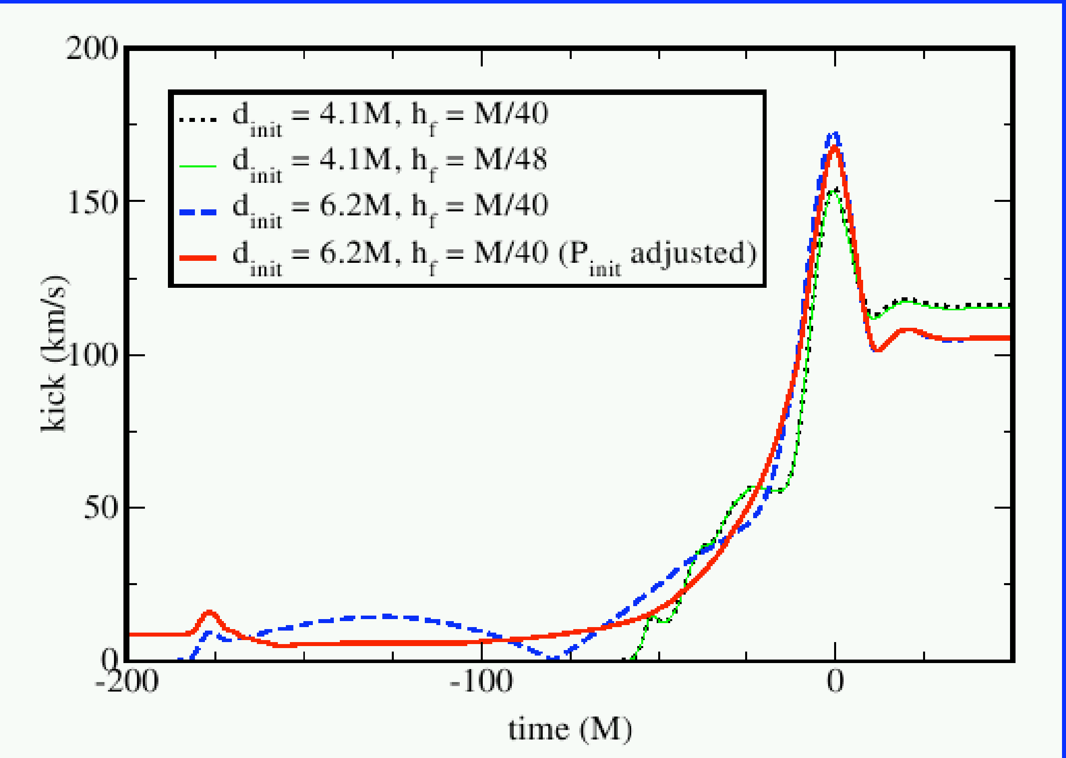


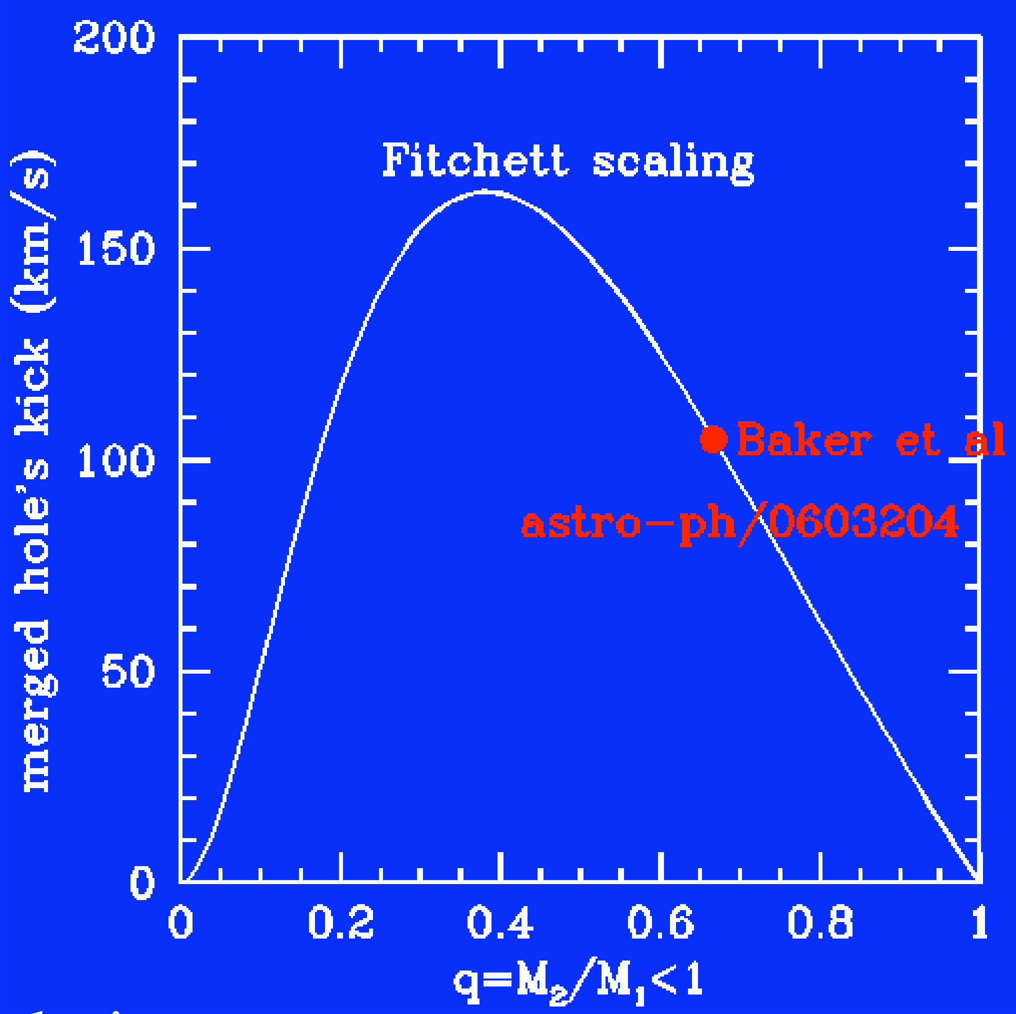


Imperfect initial data

4.6 orbits, Lindblom, Scheel, Pfeiffer 2006. Spectral method

Numerical relativity results for gravitational wave recoil





Not a major effect for Milky-Way type galaxies (sinks back in 1 Myr), but important for early dwarfs.

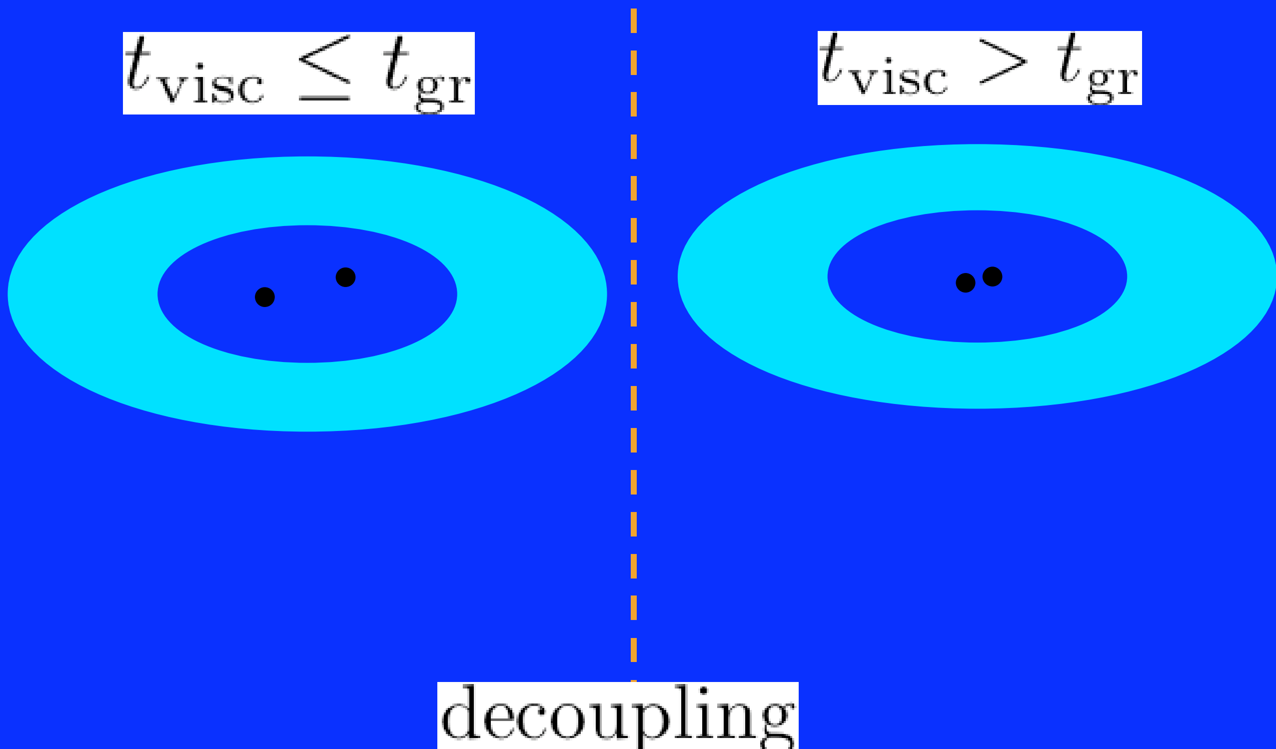
Testing GR & black hole hypothesis with ringdowns

- Complex frequency of one (known) quasi-normal mode gives M, J
- Error ~3/SNR for (l=2,m=2)
- A second known quasi-normal mode would independently give M, J, yielding consistency check.
- In practice, modes not known a priori -need another to assure correct l,m identification.
- cf Berti et al gr-qc/0512160.
- Now can be significantly tightened using numerical relativity results to specify initial amplitudes of QNMs given initial conditions measured during inspiral.
- Can also do test of area theorem (Hughes and Menou 2004).

Electromagnetic signals to provide redshift to enable D(z)?

Gas (trying to) accrete onto SMBH binary in galactic nucleus:

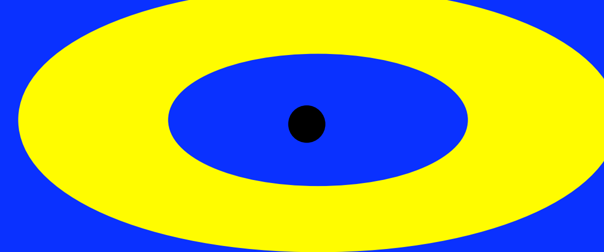
SIGNAL 1: Prompt variability (small amplitude)



Black holes merge.

$M_f \sim (1-0.02)(M_1+M_2)$

~2% mass-energy carried off in GWs



Disk perturbed: all disk particles start at pericenters of new elliptical orbits (2% epicycles). Epicyclic period varies with r, gives rise to density and T(r) variations.

Penna, Milosavljevich & Phinney 2006 ApJ sub.

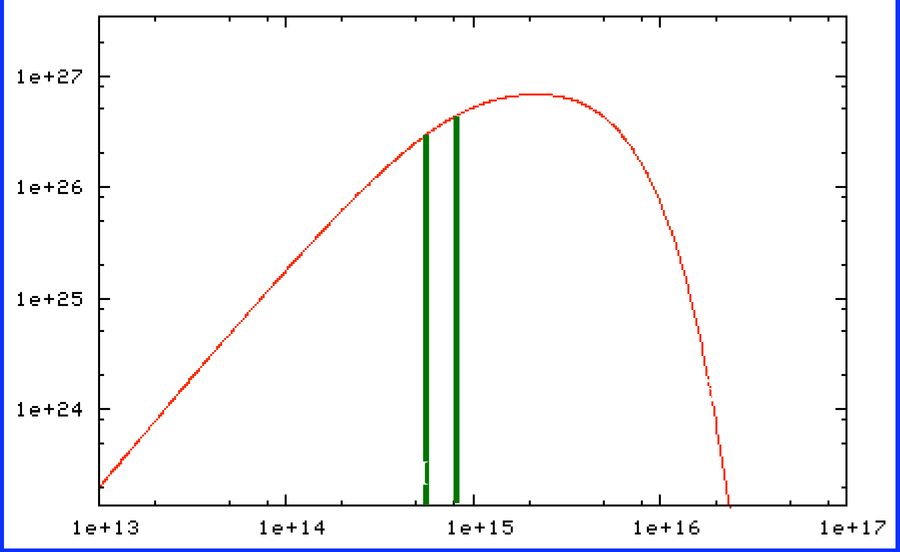
N-body Simulation I: Mass Loss Effect

Parameters

# of Particles	8000
Central Mass	10^6 M_{sun}
Inner radius	7.4 10^{12} cm
Outer Radius	1.1 10^{14} cm
Percent Mass Lost to GWs	2%
Time step	1 day

Penna, Milosavljevich & Phinney 2006 ApJ sub.

Flux(t=0)



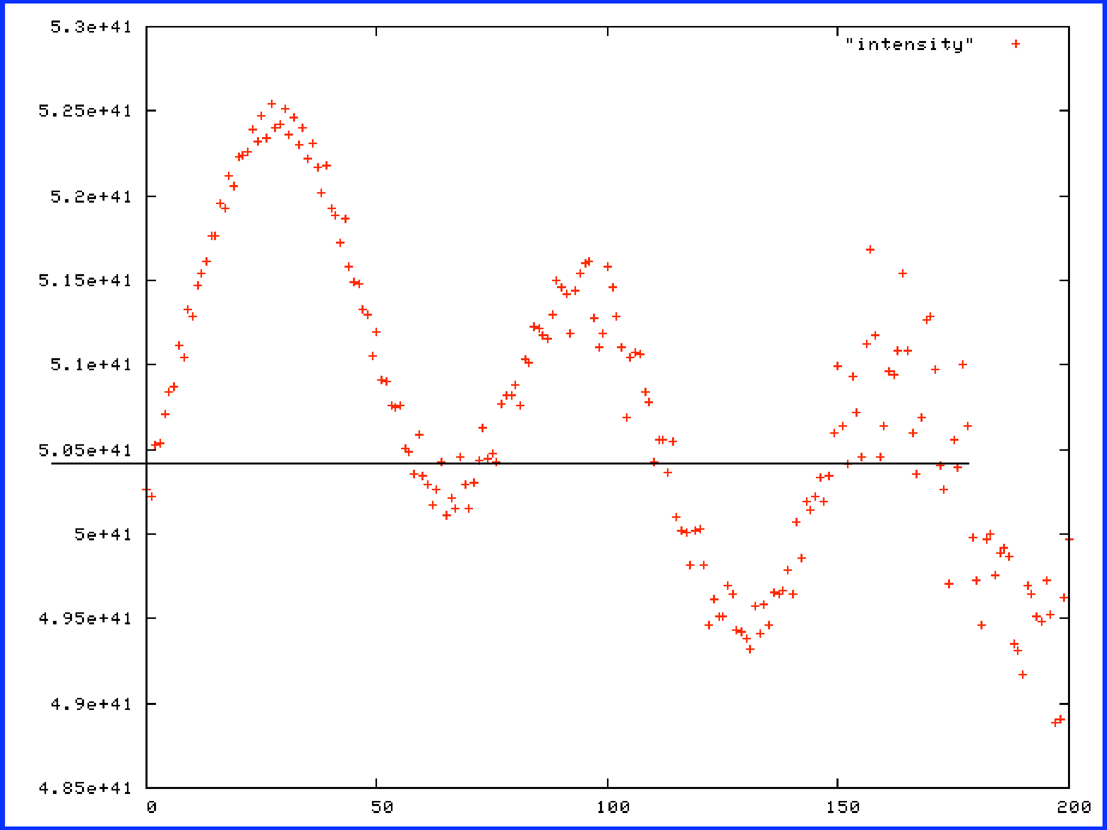
Frequency (Hz)

Even more interesting with GW recoil (not shown)!

U band flux as a function of time:

Plot assumed 2% mass loss. Variations would be +/-8% of the mean intensity, adopting new 0.04 mass loss from NR sims of equal mass non-rotating case).

Intensity [erg/s]



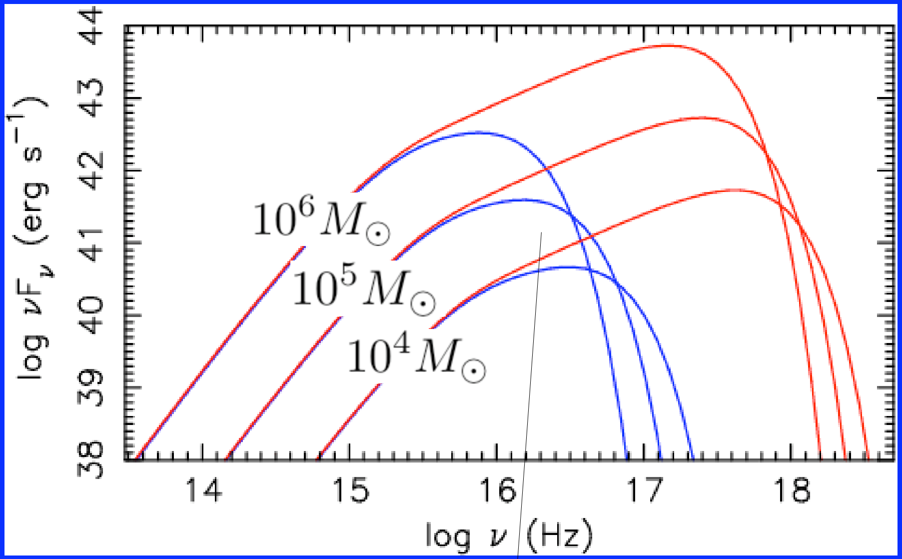
Time (days)

Penna, Milosavljevich & Phinney 2006 ApJ sub.

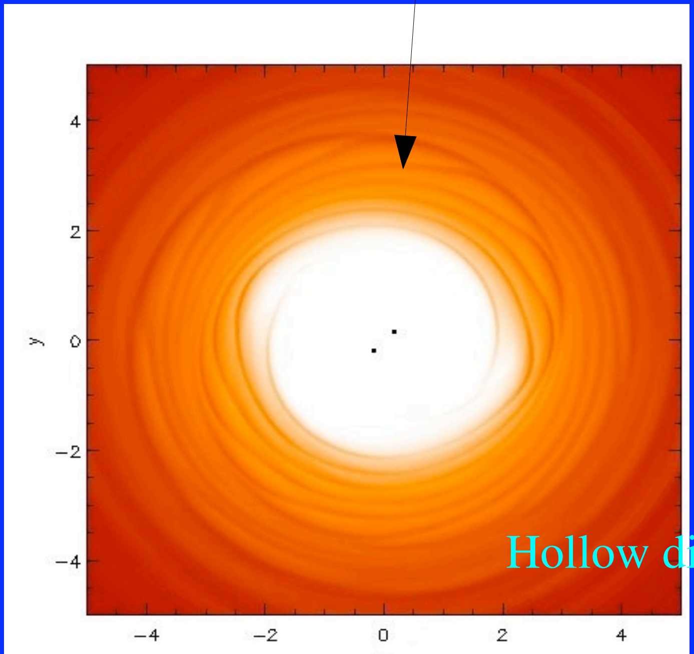
Delayed turn-on of an AGN after the merger

Milosavljevic & Phinney 2005

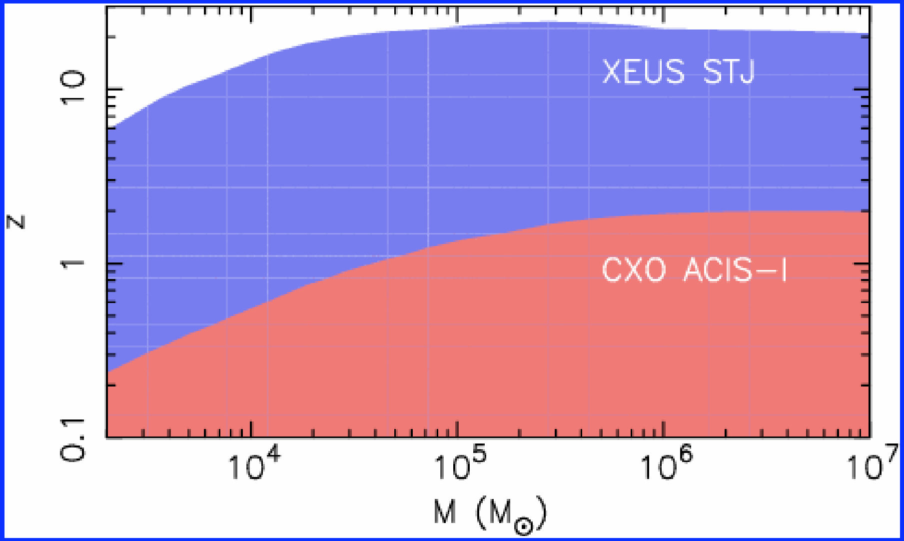
Opt UV X-ray



Thermal accretion disk spectra before and after decoupling/coalescence. Thermal X-ray emission is absent before coalescence.

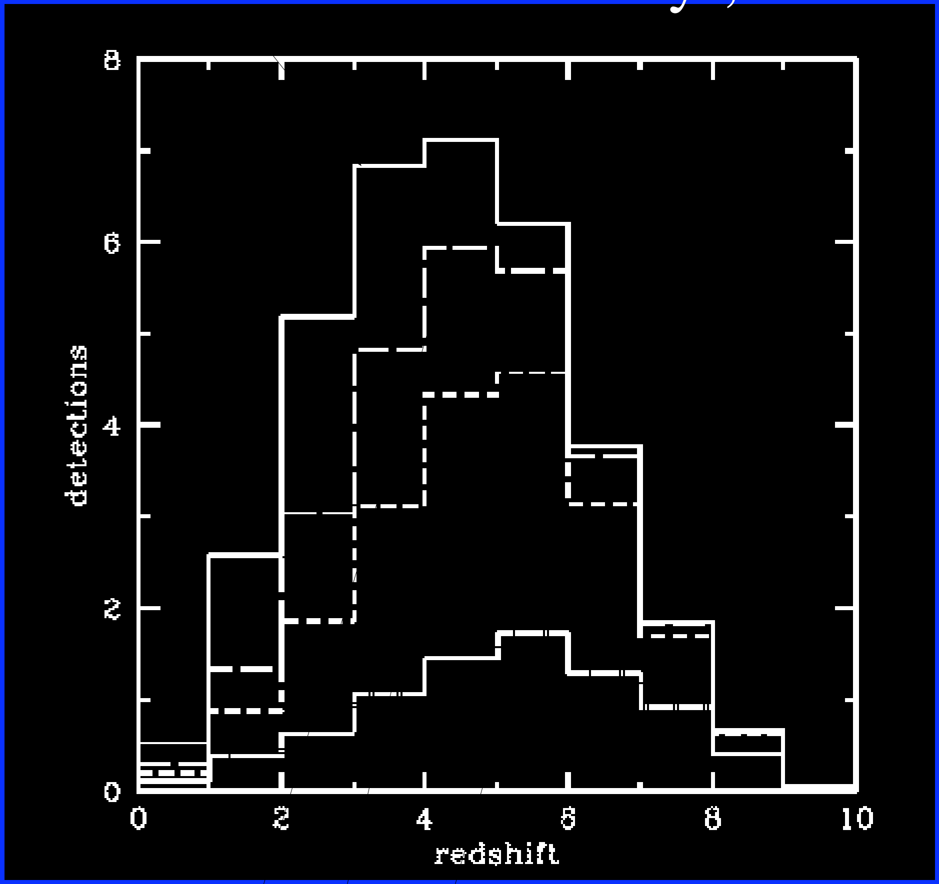


Hollow disk before merger

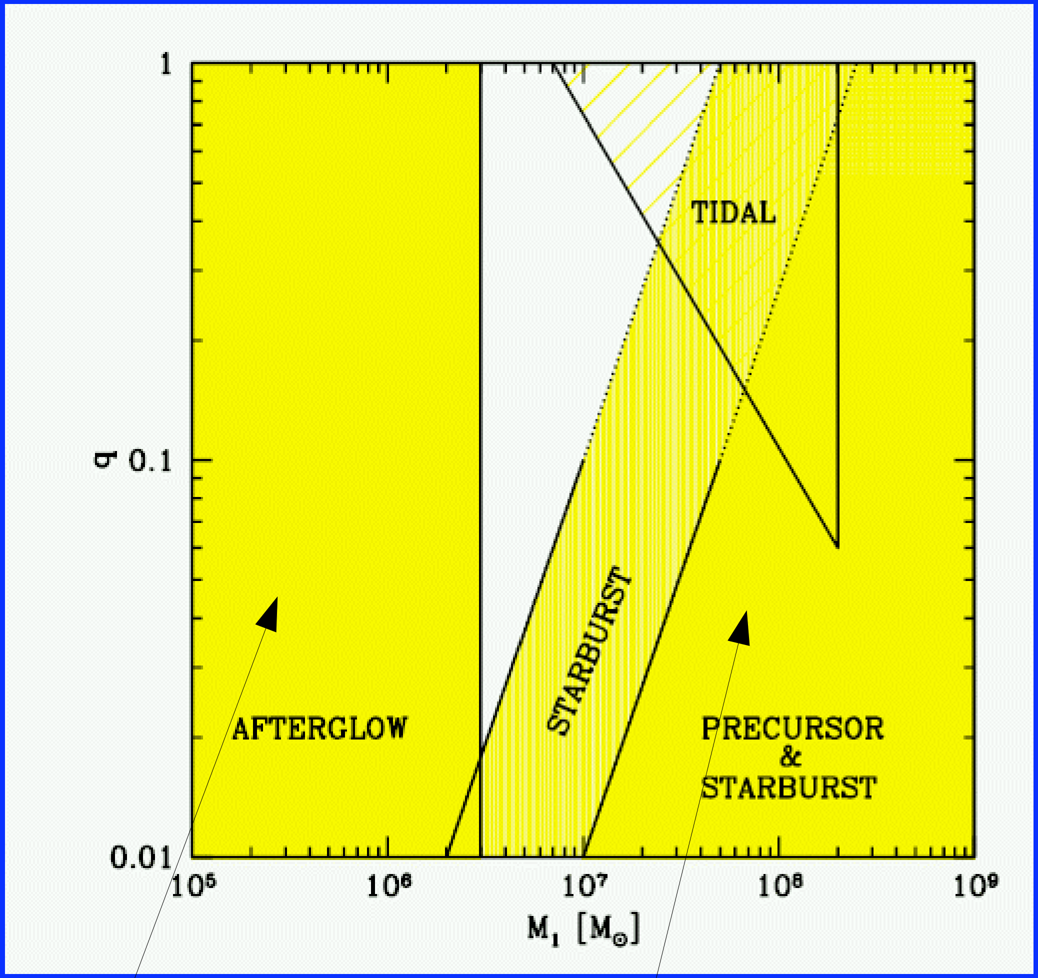


Delayed turn-on of an AGN after the merger

LISA detections in 3 yr, SNR>5



Dotti et al astro-ph/0605624



after 20, 5, 1 year

X-ray detection of afterglow by XEUS.

Circumbinary disk

Milosavljevic & Phinney 2005

Intrabinary disk

Armitage & Natarajan 2002

What good is an EM counterpart?

- Gives z, so can get high-precision D_L-z for cosmography, dark energy studies (cf Holz & Hughes astro-ph/0504616)
- Galaxy-black hole coevolution: what types of galaxies, environments?
- LISA measures both GW polarizations, so gives binary BH orbital angular momentum vector in 3d. Correlate with optically measured large-scale structure to constrain merger histories/BH growth (cf Ioka & Meszaros astro-ph/0502437)
- Mass loss due to gravitational waves gives well-defined perturbation to circumbinary disk. Oscillation period as function of observing wavelength gives radius-temperature map of accretion disk. Damping time of the oscillations gives thermal time as function of radius.
- Infill time of circumbinary disk, or evolution of precursor intrabinary disk during inspiral gives viscosity of disk.

EM SIGNAL 2: Delayed variability (LARGE amplitude)

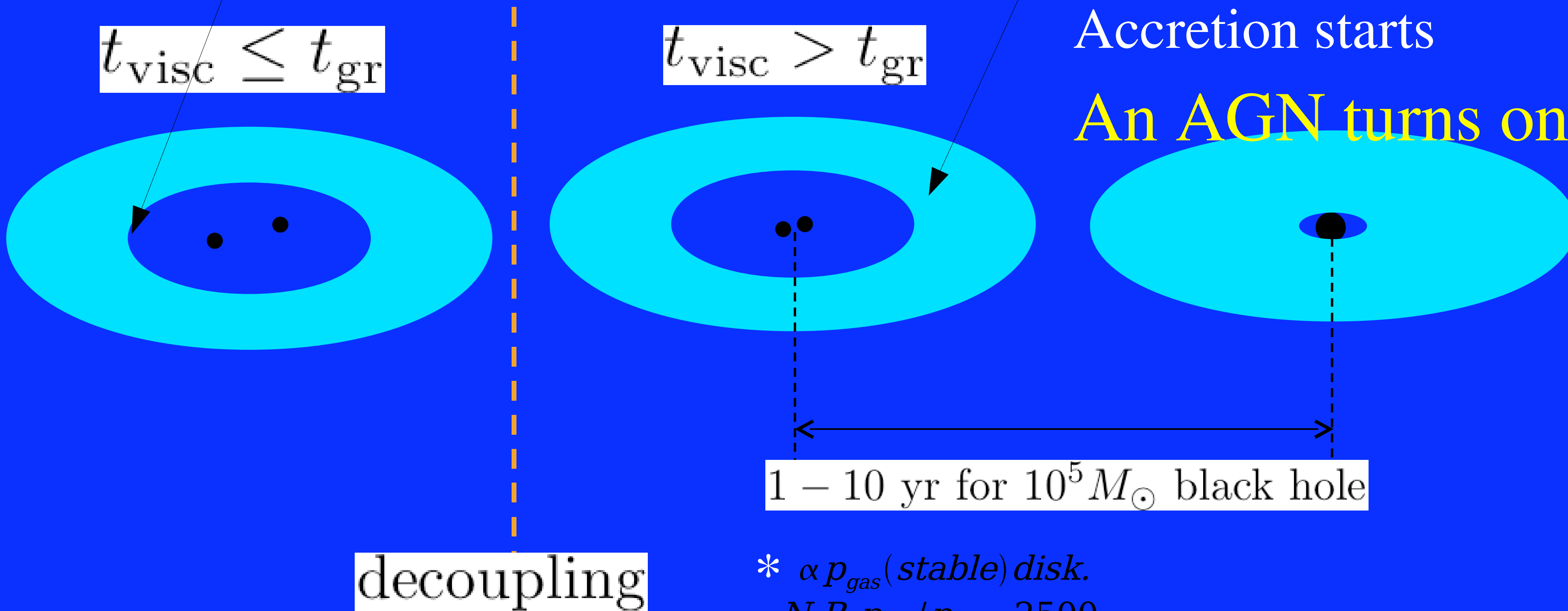
Gas trying to accrete onto SMBH binary in galactic nucleus:

Prevented by gravitational torques from binary: hollow disk.

Fills after merger

Accretion starts

An AGN turns on!



* $\alpha\, p_{gas}$ (*stable*) *disk.*
N.B. $p_{rad}/p_{gas} \sim 2500$.

Milosavljevic & Phinney 2005, ApJL 622, L93 = astro-ph/0410343

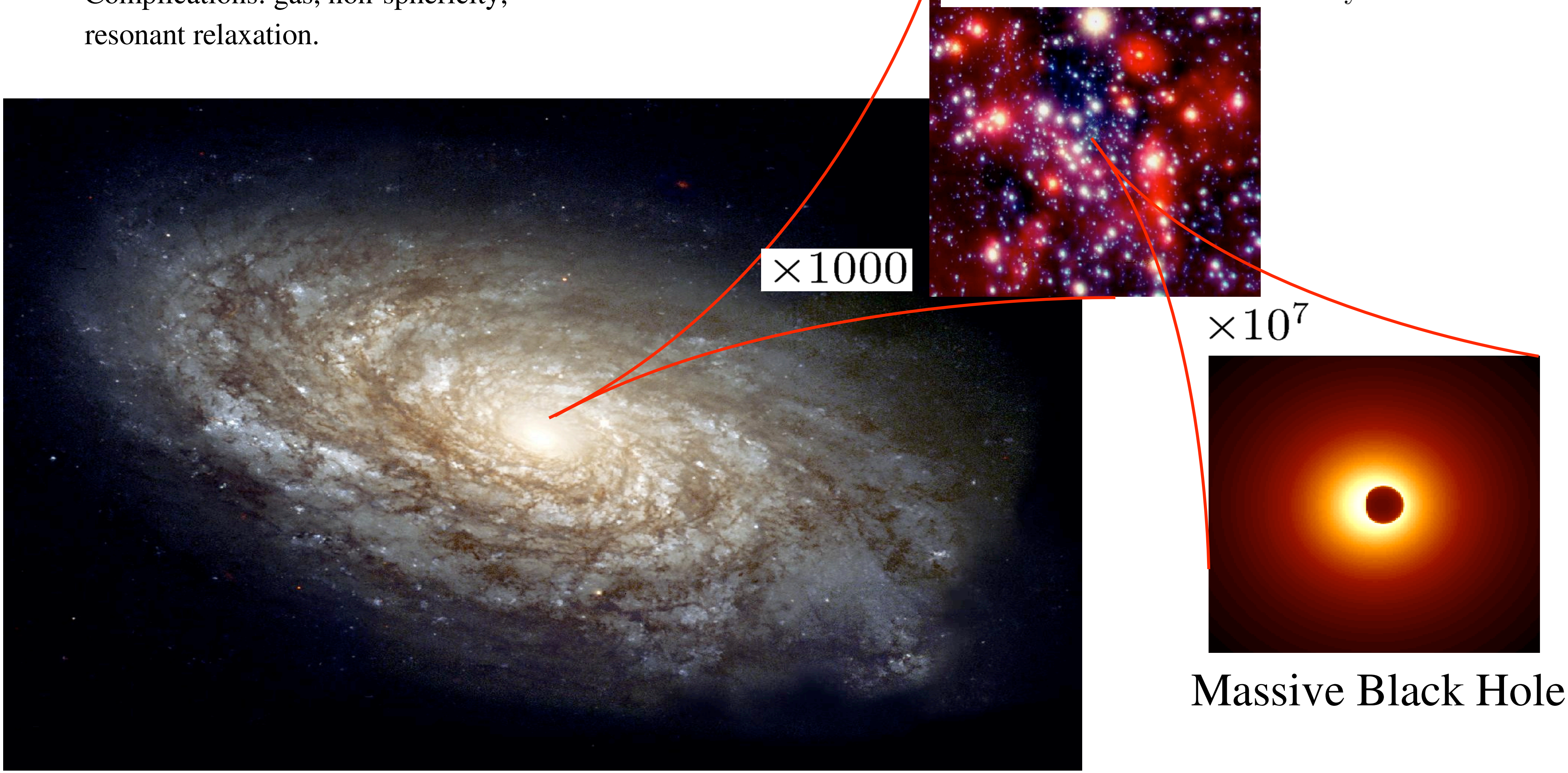
The Final Decade*

Capture of stellar mass (or IMBH) objects by nuclear black holes

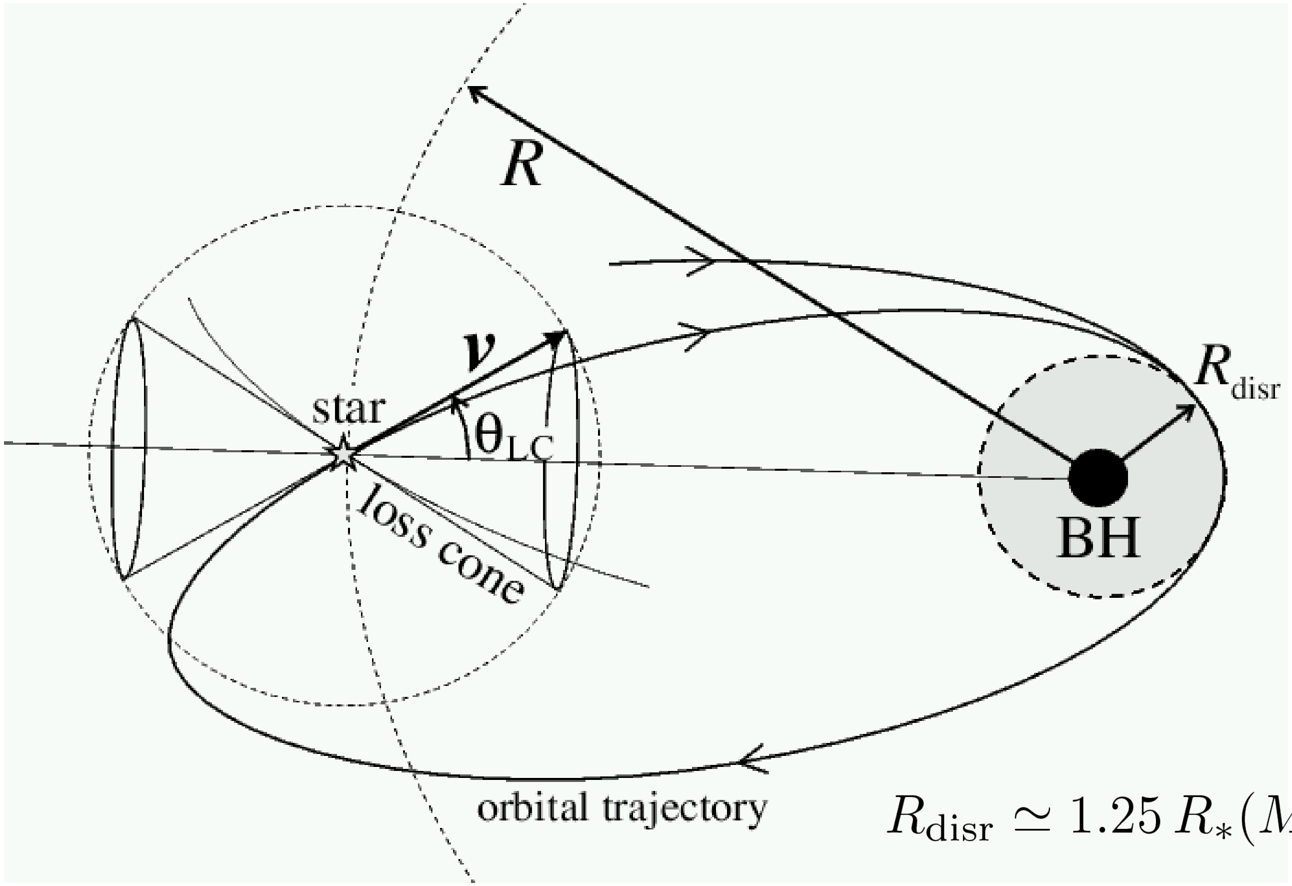
2-body relaxation important short
Black hole dominates inside ~pc.
Complications: gas, non-sphericity, resonant relaxation.

Galactic nucleus

Size	$\sim 1 - 10\,\mathrm{pc}$
Density	$\sim 10^7\,\mathrm{M}_\odot\mathrm{pc}^{-3}$
Velocity dispersion	$\sim 100 - 1000\,\mathrm{km\,s}^{-1}$
Relaxation time	$\sim 10^{8-9}$ years



Loss Cone



$$R_{\rm disr} \simeq 1.25\, R_*(M_{\rm BH}/M_*)^{1/3}$$

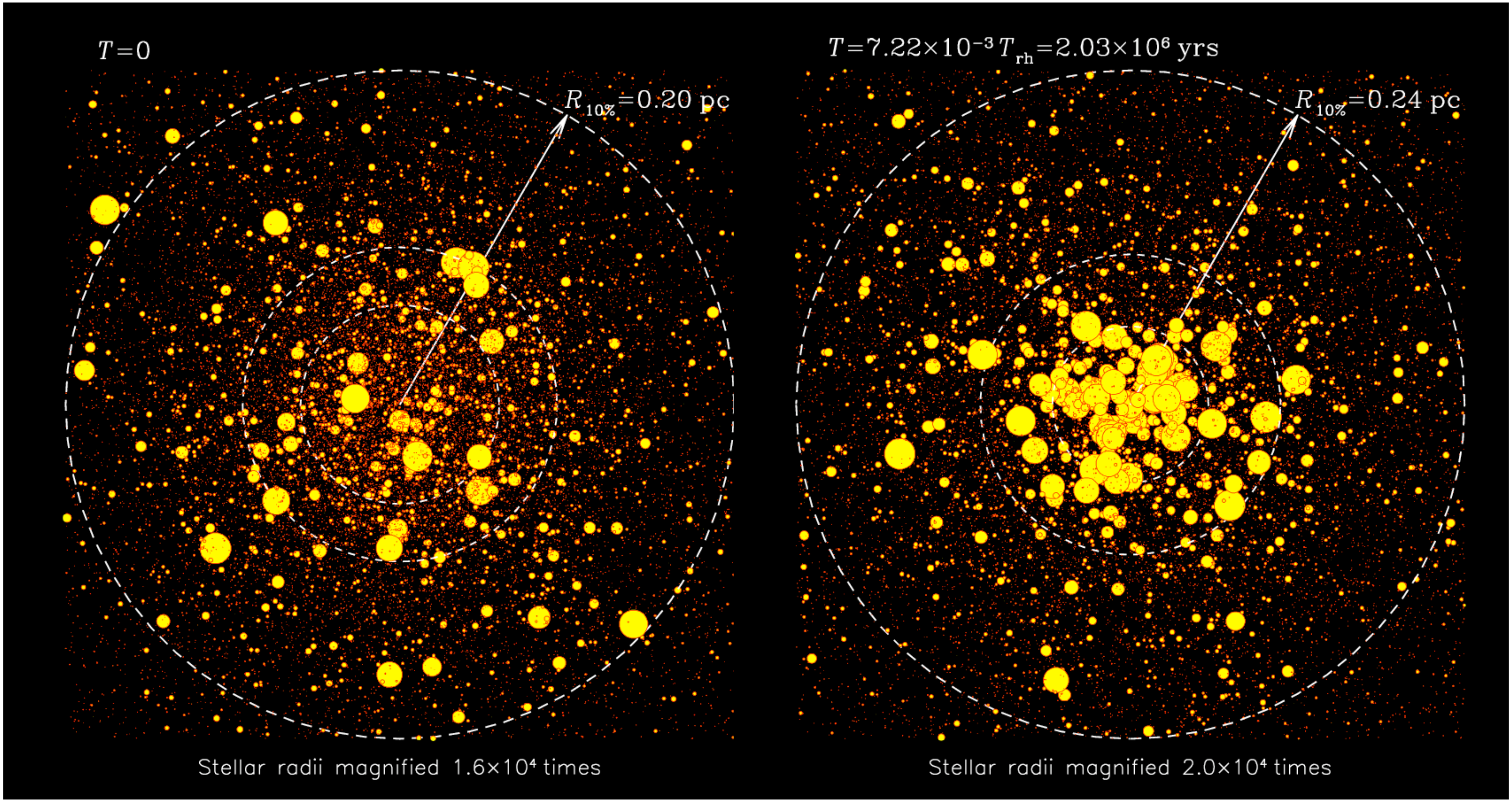
Loss cone apperture: $$J < J_{\rm LC} \simeq \sqrt{2GM_{\rm BH}R_{\rm disr}}$$

$$\theta_{\rm LC} \simeq \frac{J_{\rm LC}}{Rv} \approx \sqrt{\frac{R_{\rm disr}}{R}}$$

Mass segregation without a MBH

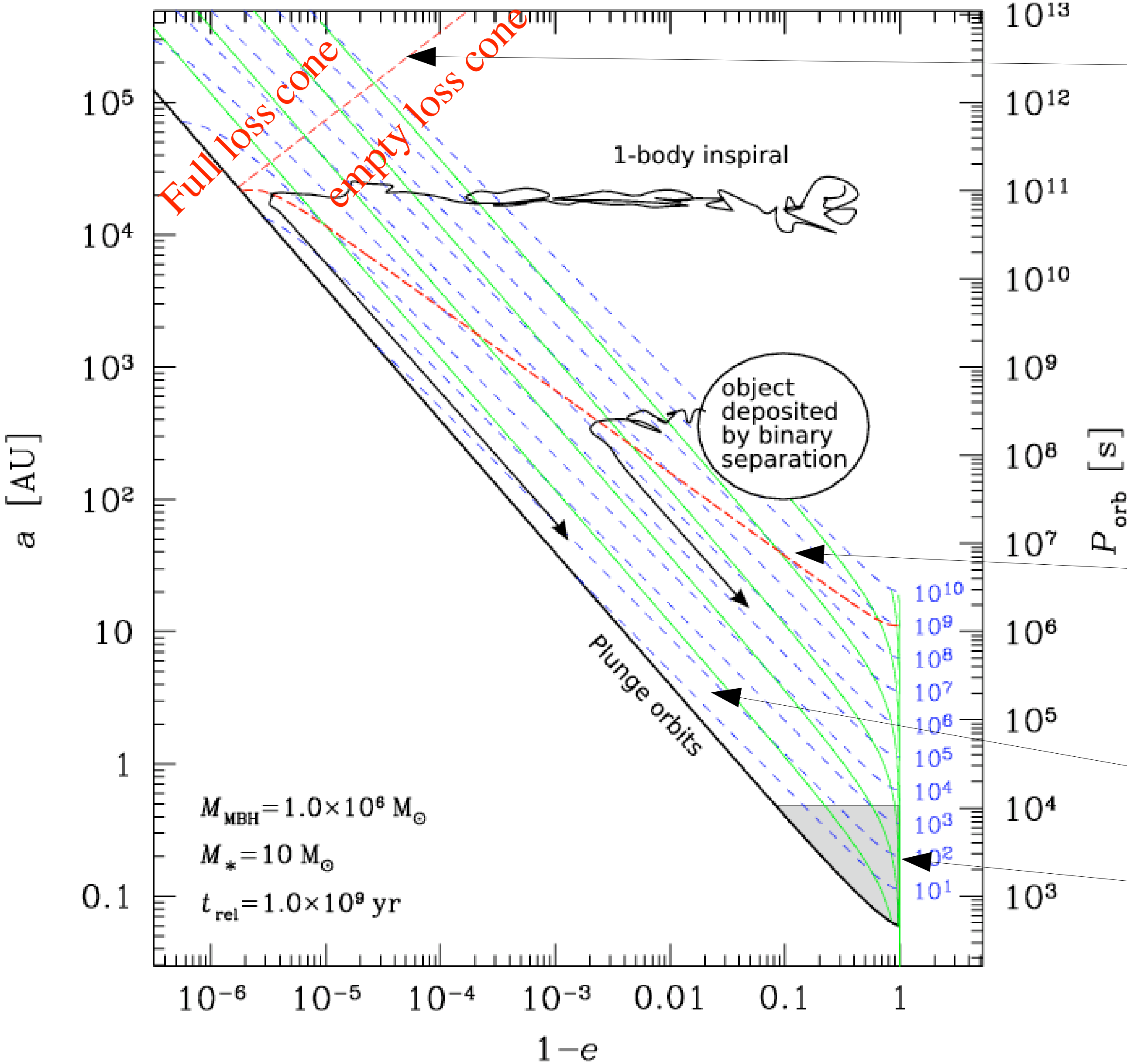
Initial conditions

Core collapse



Gürkan, Freitag & Rasio 2004; Freitag, Rasio & Baumgardt 2005

EMR Inspiral (ENRI) in (e,a) plane



Time to scatter periapse = (1-e) relaxation time = orbital period.

For possible contribution of "binary splitting", see Miller et al. 2005

Relaxation time = gravitational wave loss time.

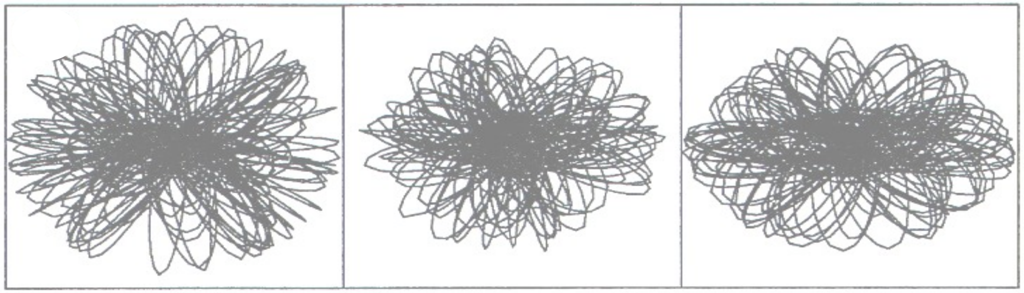
bursts in LISA band.

continuously in LISA band.

Simpified: no resonant relaxation, no oblateness or triaxiality disguises diffusion across boundaries.

EMRI astrophysics

- Relaxation plays a role on time scales << t_{rlx}
- LISA detection rates dominated by stellar BHs, IMBH?
  - Mass segregation is key
  - Role of natal kicks?
- Effects of non-sphericity (centrophilic orbits)



Poon & Merritt 01

- Star interaction/formation with/in accretion disk
  - cf. Galactic center: Paumard et al 2005, Beloborodov astro-ph/0601273: two counter-rotating disks of 6Myr old OB stars, 5000Msun -no low mass stars -non-Salpeter. Can't happen more than once per 100Myr or overproduce!
  - Continued supply of BHs. Also Levin astro-ph/0603583: stars formed embedded in disk lose angular momentum to density waves, forced to migrate in in <1Myr. S-stars and circular EMRIs/tidal events?

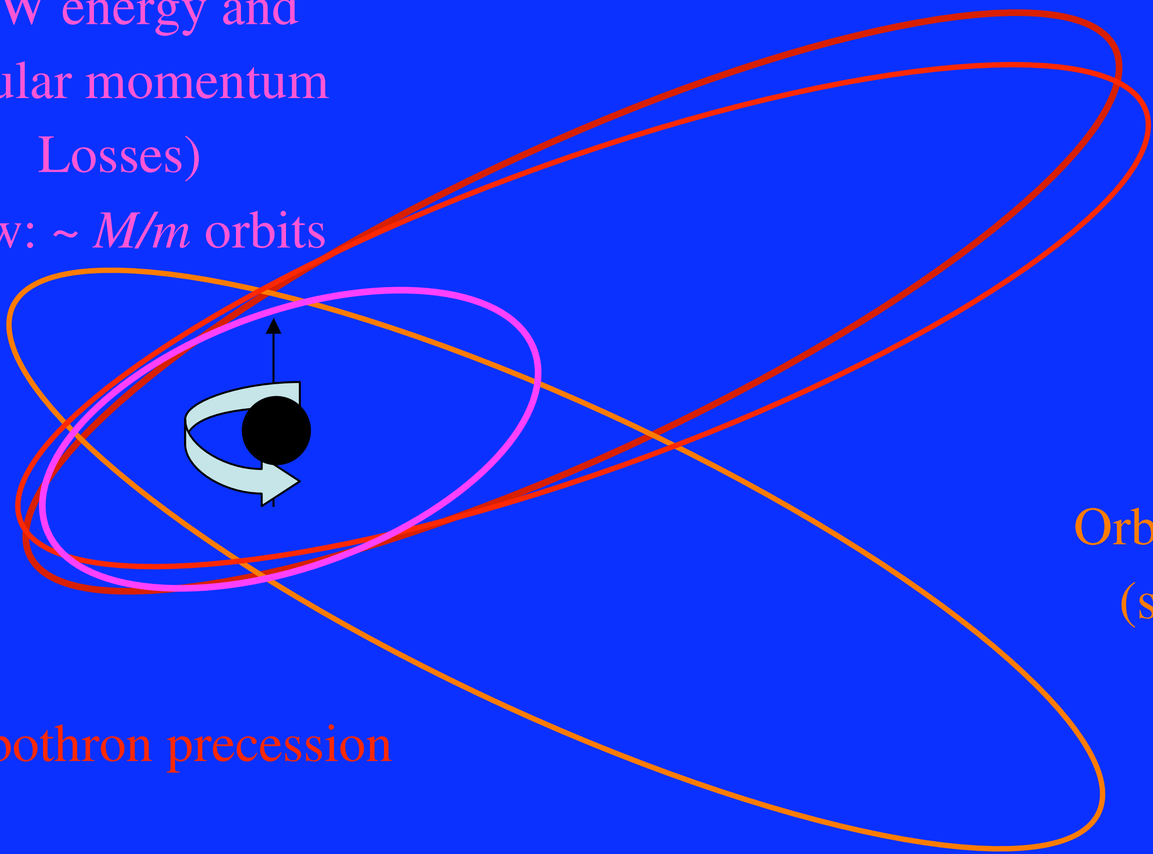
Rates of EMRI

- Dominated by M<3E6 Msun black holes -only a few known -assume >10% of galaxies have them (Greene et al 2006) = extrapolation of well-determined z=0 supermassive black hole mass function at higher mass.
- Unrealistically pessimistic: no resonant relaxation, NO stellar mass black holes (only WD), spherical cluster, diffusive outscattering: 1-2/yr at SNR>35.
- `reasonable': stellar mass black hole Salpeter IMF, resonant relaxation, diffusive outscattering, spherical cluster, no continued black hole formation: 30/yr at SNR>35.
- `upper limit': continued black hole formation from gas, triaxial bar or disk-driven migration, flat IMF (as observed in Galactic Center disks): 250/yr at SNR>35.

Orbits and spiral-in of small bodies around spinning black holes (EMRI)

Extreme Mass Ratio Inspirals

Spiral-in and Circularization (GW energy and angular momentum Losses)
Slow: ~ *M/m* orbits



Orbit plane precession (spin – orbit; L-T)

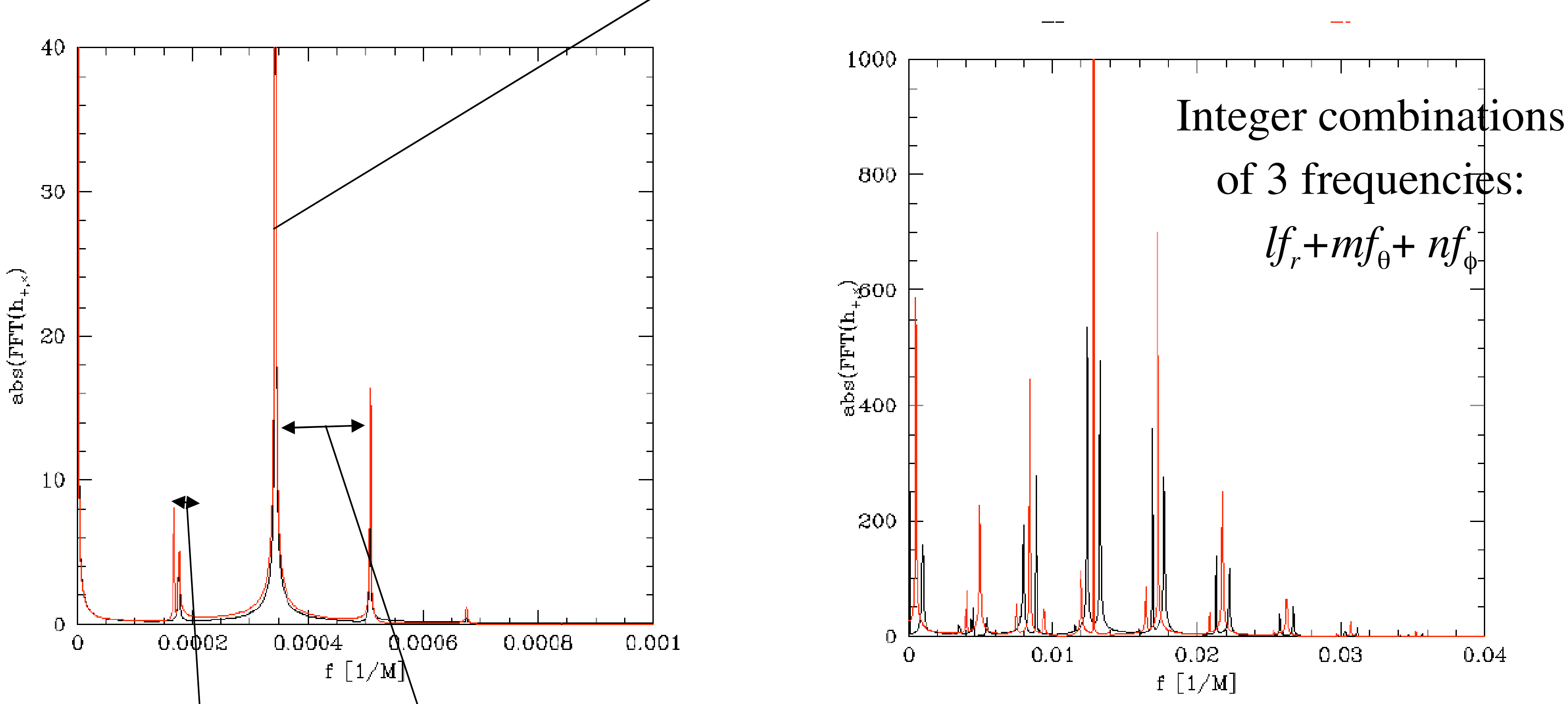
Peribothron precession

Fourier spectra of gravitational wave forms from EMRI

2x orbital freq

a*=0.9, a=100M, e=0.05, i=45

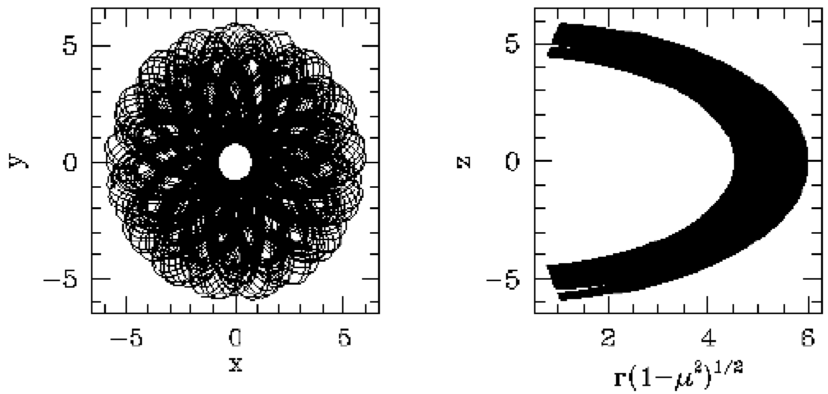
a*=0.9, a=10M, e=0.2, i=45

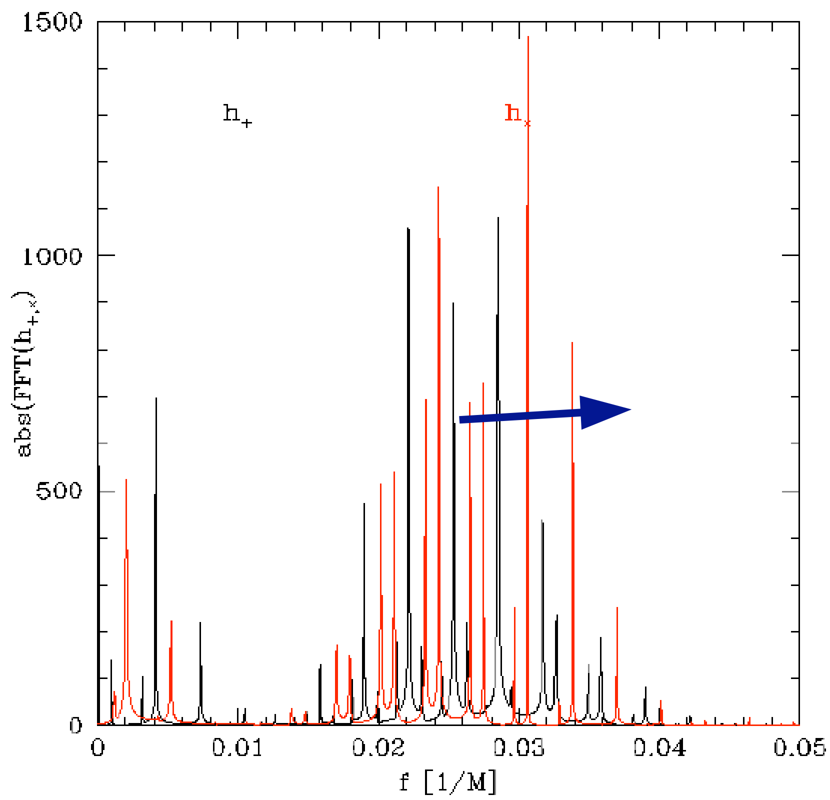


L-T orbit plane precession freq

Peribothron precession freq

a*=0.95, a=6M, e=0.2, i=80





Frequencies sweep and shift slowly as the compact object spirals in, mapping space-time outside the horizon. cf. geodesy satellites mapping geopotential: bothrodesy.

At each instant, all frequencies are integer sums of f_r f_φ f_θ. So can measure $f_r(f_\varphi)$ *and* $f_\theta(f_\varphi)$. Theory (e.g. vacuum GR) predicts these functions as powerseries in $f_\varphi^{1/3}$ with coefficients redundantly determined by the exterior multipole moments of the spacetime. (Ryan 1995 PRD 52, 5707 equatorial; Lovelace, Li attempting general). Read off multipoles, test no-hair theorem.

Precision of EMRI parameter determination

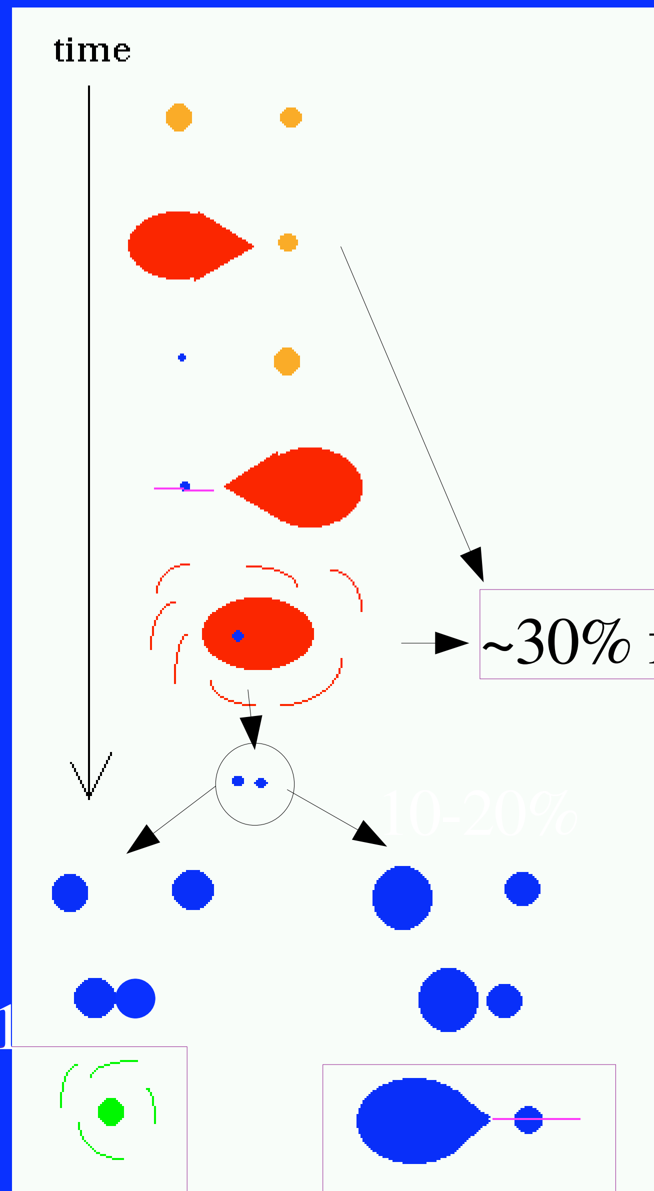
S/M^2	0.1	0.1	0.1	0.5	0.5	0.5	1	1	1
$e_{\rm LSO}$	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5
$\Delta(\ln M)$	2.6e−4	5.6e−4	5.3e−5	2.7e−4	9.2e−4	7.7e−5	2.8e−4	2.5e−4	1.5e−4
$\Delta(S/M^2)$	3.6e−5	7.9e−5	4.5e−5	1.3e−4	6.3e−4	5.1e−5	2.6e−4	3.7e−4	2.6e−4
$\Delta(\ln \mu)$	6.8e−5	1.5e−4	7.4e−5	6.8e−5	9.2e−5	1.0e−4	6.1e−5	9.1e−5	1.0e−3
$\Delta(e_0)$	6.3e−5	1.3e−4	2.9e−5	8.5e−5	2.8e−4	3.2e−5	1.2e−4	1.1e−4	1.6e−4
$\Delta(\cos\lambda)$	6.0e−3	1.7e−2	1.3e−3	1.3e−3	5.8e−3	2.4e−4	6.5e−4	8.4e−4	4.7e−4
$\Delta(\Omega_s)$	1.4e−3	1.6e−3	6.3e−4	1.4e−3	2.1e−3	6.3e−4	1.4e−3	8.3e−4	6.2e−4
$\Delta(\Omega_K)$	5.6e−2	5.5e−2	4.7e−2	5.5e−2	5.2e−2	4.7e−2	5.5e−2	5.1e−2	4.8e−2
$\Delta(\tilde{\gamma}_0)$	4.0e−1	6.3e−1	3.8e−1	1.0e+0	6.1e−1	3.9e−1	9.3e−1	3.4e−1	3.9e−1
$\Delta(\Phi_0)$	2.6e−1	6.7e−1	2.2e−1	1.4e+0	7.5e−1	2.7e−1	1.5e+0	1.7e−1	3.3e−1
$\Delta(\alpha_0)$	6.2e−1	5.8e−1	5.5e−1	6.3e−1	5.9e−1	5.6e−1	6.4e−1	5.9e−1	5.9e−1
$\Delta[\ln(\mu/D)]$	8.7e−2	3.8e−2	3.7e−2	3.8e−2	3.7e−2	3.7e−2	3.8e−2	7.0e−2	3.7e−2
$\Delta(t_0)\nu_0$	4.5e−2	1.1e−1	3.3e−2	2.3e−1	1.3e−1	4.4e−2	2.5e−1	3.2e−2	5.5 − 2

TABLE III. Parameter accuracy estimates for inspiral of a $10M_\odot$ CO onto a $10^6 M_\odot$ MBH at SNR=30 (based on data collected during the last year of inspiral). Shown are estimates for the accuracy in determining the various physical parameters, for various values of the MBH's spin magnitude S and the final eccentricity $e_{\rm LSO}$. The rest of the parameters are set as follows: $t_0 = (1/2)$yr (middle of integration); $\tilde{\gamma}_0 = 0$; $\Phi_0 = 0$; $\theta_S = \pi/4$; $\phi_S = 0$; $\lambda = \pi/6$; $\alpha_0 = 0$; $\theta_K = \pi/8$; $\phi_K = 0$.

$$\frac{\delta \text{mass}}{\text{mass}} \simeq 10^{-4}\ , \qquad \frac{\delta \text{spin}}{\text{spin}} \simeq 10^{-4}$$

Barak & Cutler 2004

White dwarf binaries



~30% failed envelope ejection

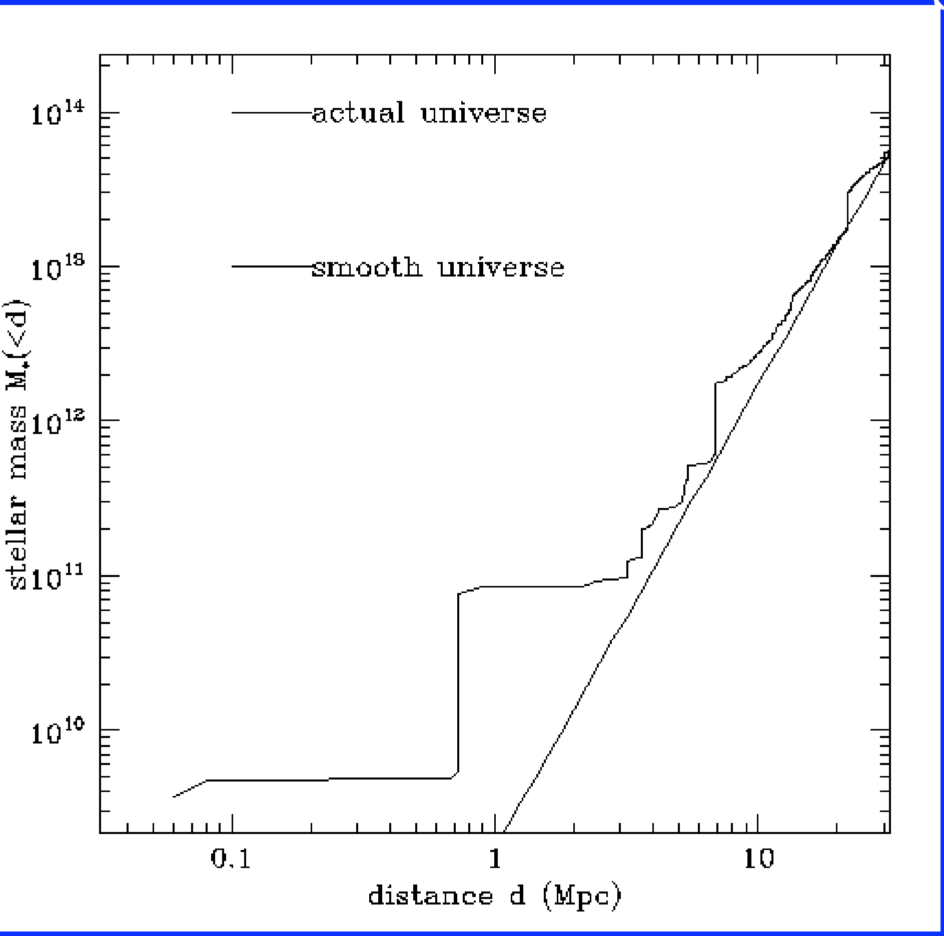
SNIa, massive
white dwarf,
dolichonova (V838Mon,
M31-RV, M85-OT2006-1
AIC, magnetar,

AM CVn

LISA
source

- fairly well determined (factor of few) by both
  - theory: created by common envelope inspiral of initially wide binaries. Depends on
    - binary fraction & mass ratio distribution as function of M_1
    - common envelope ejection efficiency α_{CE} (weakly sensitive). $\alpha_{CE} |\Delta E_{orbit}| > |E_{b,envelope}|$ for CE ejection.
    - angular momentum transport (e.g. by tides) and mass loss $\Rightarrow$ mass transfer stability
  - observation: we see many WD-WD pairs that will merge (esp. recent SPY survey), plus likely aftermaths. Observational rates agree roughly with theoretical ones.

LISA will detect ~10^4 binary WDs in the Milky Way + ~100 in globulars, Magellanic clouds



Scaling to the rest of the universe gives volume-average z=0 rates

He+He: $4\times10^{-5}\,\mathrm{Mpc}^{-3}\mathrm{y}^{-1}$

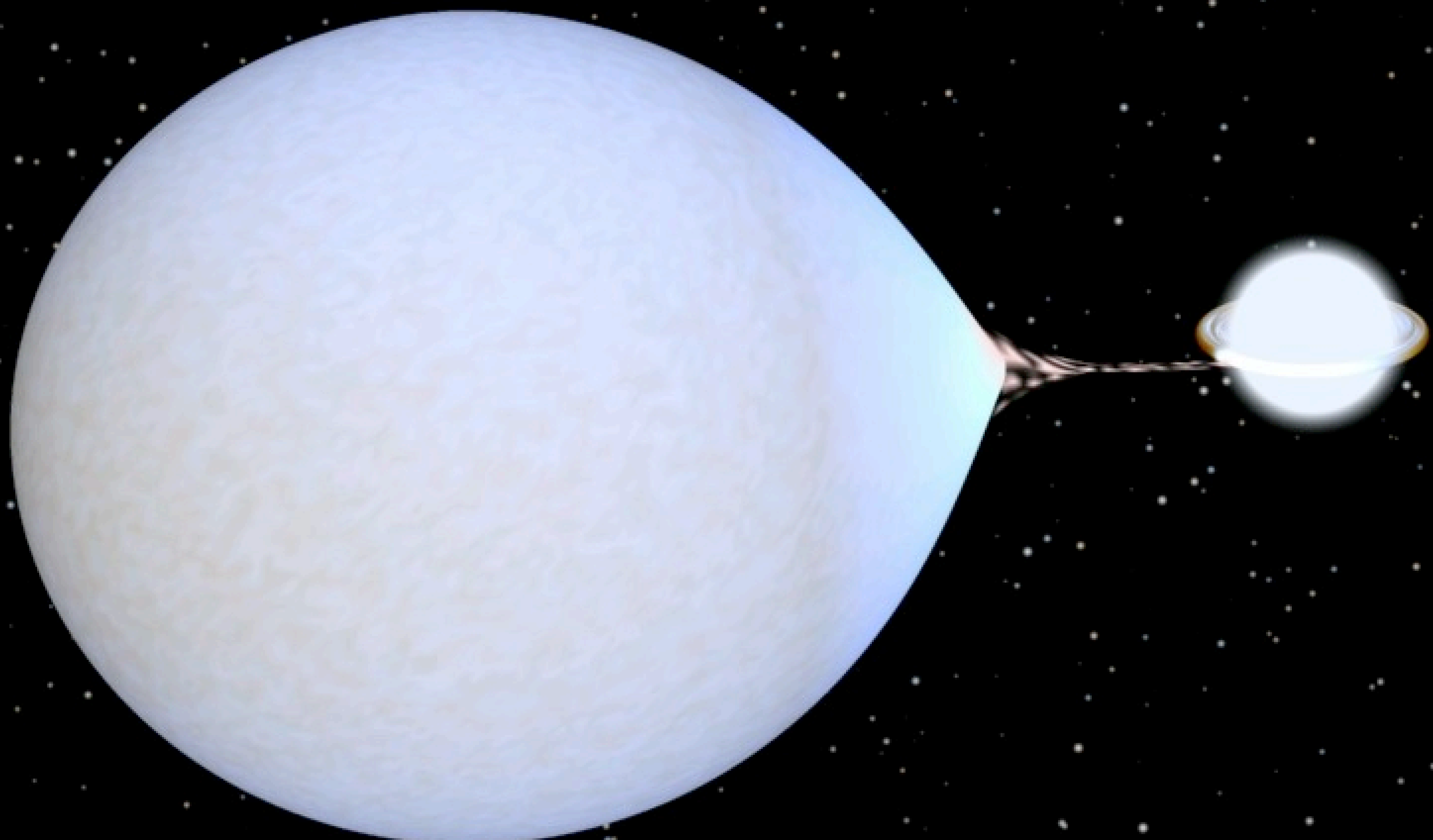
He+CO: $2\times10^{-4}\,\mathrm{Mpc}^{-3}\mathrm{y}^{-1}$

CO+CO: $6\times10^{-5}\,\mathrm{Mpc}^{-3}\mathrm{y}^{-1}$

Given the Virgo enhancement above the mean density, these rates give D(1/y)~7-10Mpc.

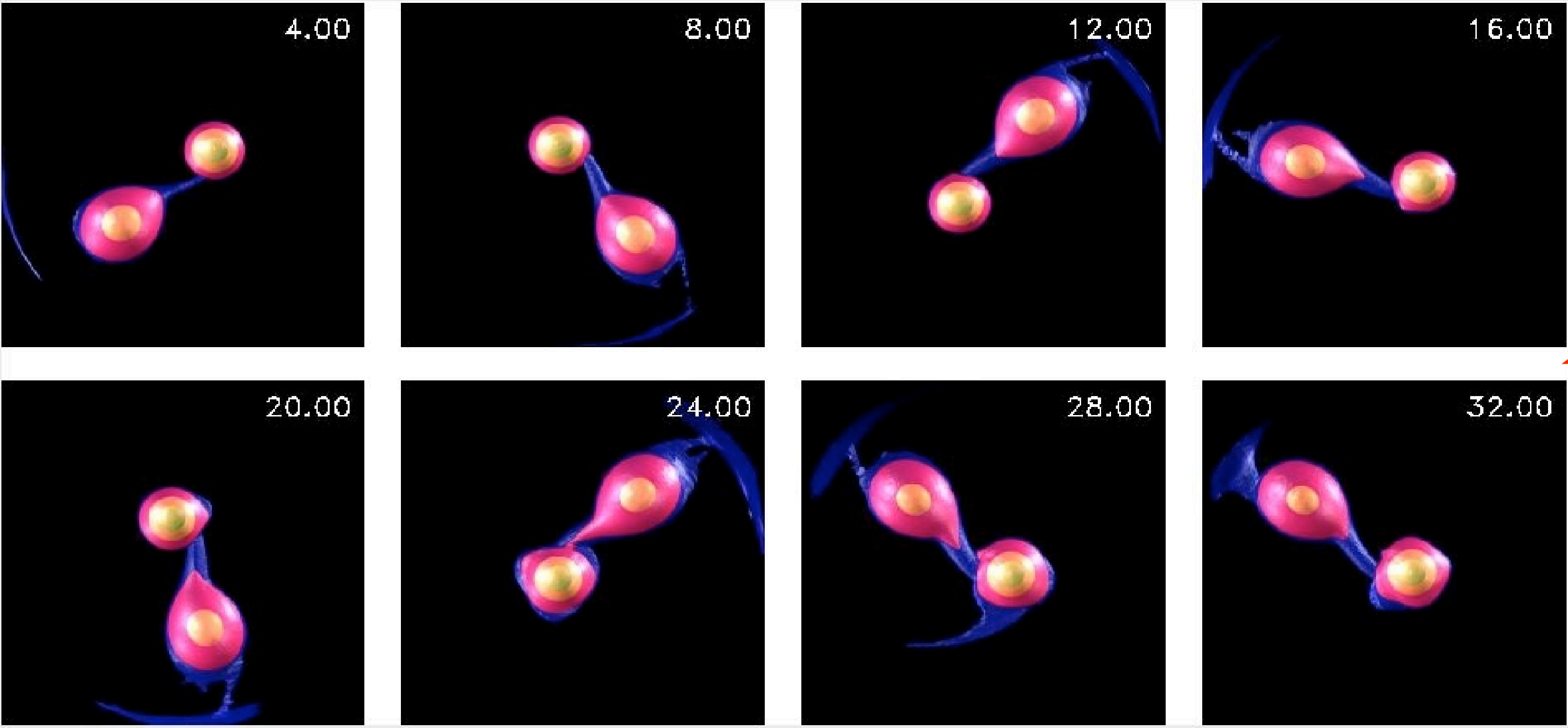
- Degenerate stars: less massive bigger, fills Roche lobe first. $q=M_{loser}/M_{gainer}$. WDs not subject to tidal instability as are stiffer NS's (cf. Lai et al 1993 ApJ 406, L63)
- If angular momentum of accreted material conserved (no mass loss) and transferred back to orbit (by disk tides or stellar tides)
  - When mass transfer starts, if $q>0.6$ mass loser swells faster than Roche lobe: dynamical instability.
  - If $q<0.6$, mass loser swells more slowly than growing Roche lobe: dynamically stable.
  - If $q<0.22$, stable even without tides to transfer angular momentum back to orbit.
  - Limiting understanding: white dwarf tides, mass loss, disk dynamics and direct impact physics. Affects stability (Soberman et al 1997 AA 327, 620) of transfer and dM/dt.

The skeleton in the closet:



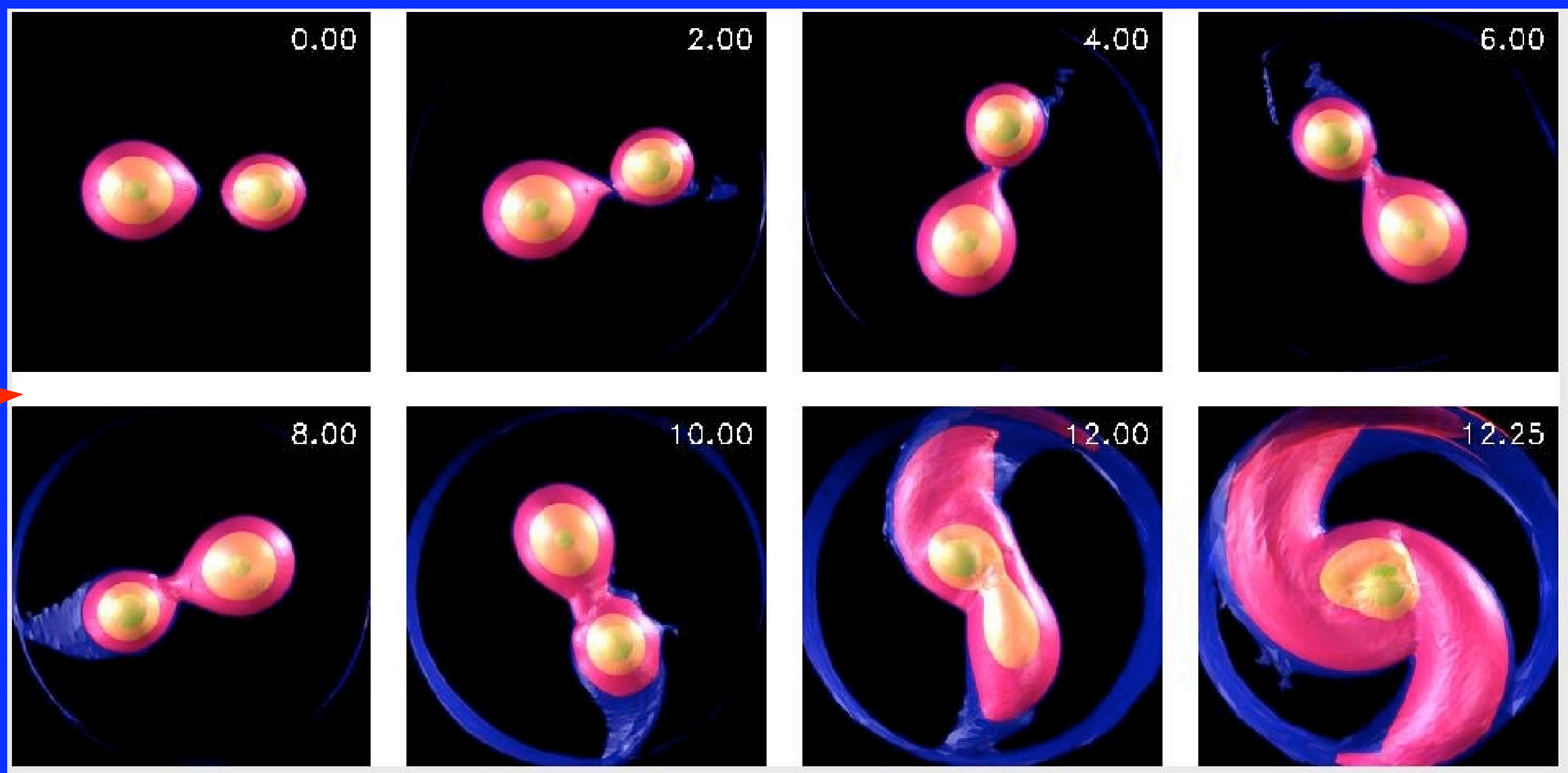
RXJ0806.3+1527, P_b=5min, direct impact. dP_b/dt right magnitude, wrong sign for conservative GR-driven evolution. L_X too low by orders of magnitude. Must be below equilibrium transfer rate. Also V407 Vul. Note that tides can dissipate rotation energy ~WD's grav binding energy! Need to understand tides in white dwarfs!

- Smooth Particle Hydro (SPH) simulations seem to make everything disrupt (even q=0.5: Rasio & Shapiro 1995 ApJ 438, 887 and q=0.33: Guerrero et al 2004 A&A 413, 257).
- More accurate Eulerian hydro simulations (D'Souza et al astro-ph/0512137) disrupt q=1.3 as expected, but find q=0.5 to be dynamically stable as expected theoretically and in contrast to the SPH results.



q=0.5

MOVIE TIME



q=1.3

D'Souza et al
astro-
ph/0512137

Proposed aftermaths of WD-WD merger

- Single subdwarf OB (sdB, sdO) stars: He+He
- R Coronae Borealis (R CrB) stars: He+CO
- EUVE J0317-85.5 rapidly rotating 1.35Msun, magnetic white dwarf: CO+CO
- Most single white dwarfs with M>0.7Msun.
- Neutron stars: accretion induced collapse CO+ONeMg, ONeMg+ONeMg
  - single msec pulsars (weakly magnetised WDs)
  - magnetars/AXPs/SGRs (strongly magnetised Wds)
- Type Ia Supernovae. Ib/c ???

What will LISA contribute?

- Can measure braking index of ~20 shortest period wd binaries to 0.3 (vs 11/3 for point mass, noninteracting). Test theories of tides, mass xfer.
- Masses (if SIM or GAIA distances, or n=11/3.)
- 25% eclipsing, get M, R. *Dramatic tidal heating very likely*. Optically bright sources.
- Synchronisation in direct impact? r-mode offset?
- Effects of resonant mode excitation on spin, orbit.

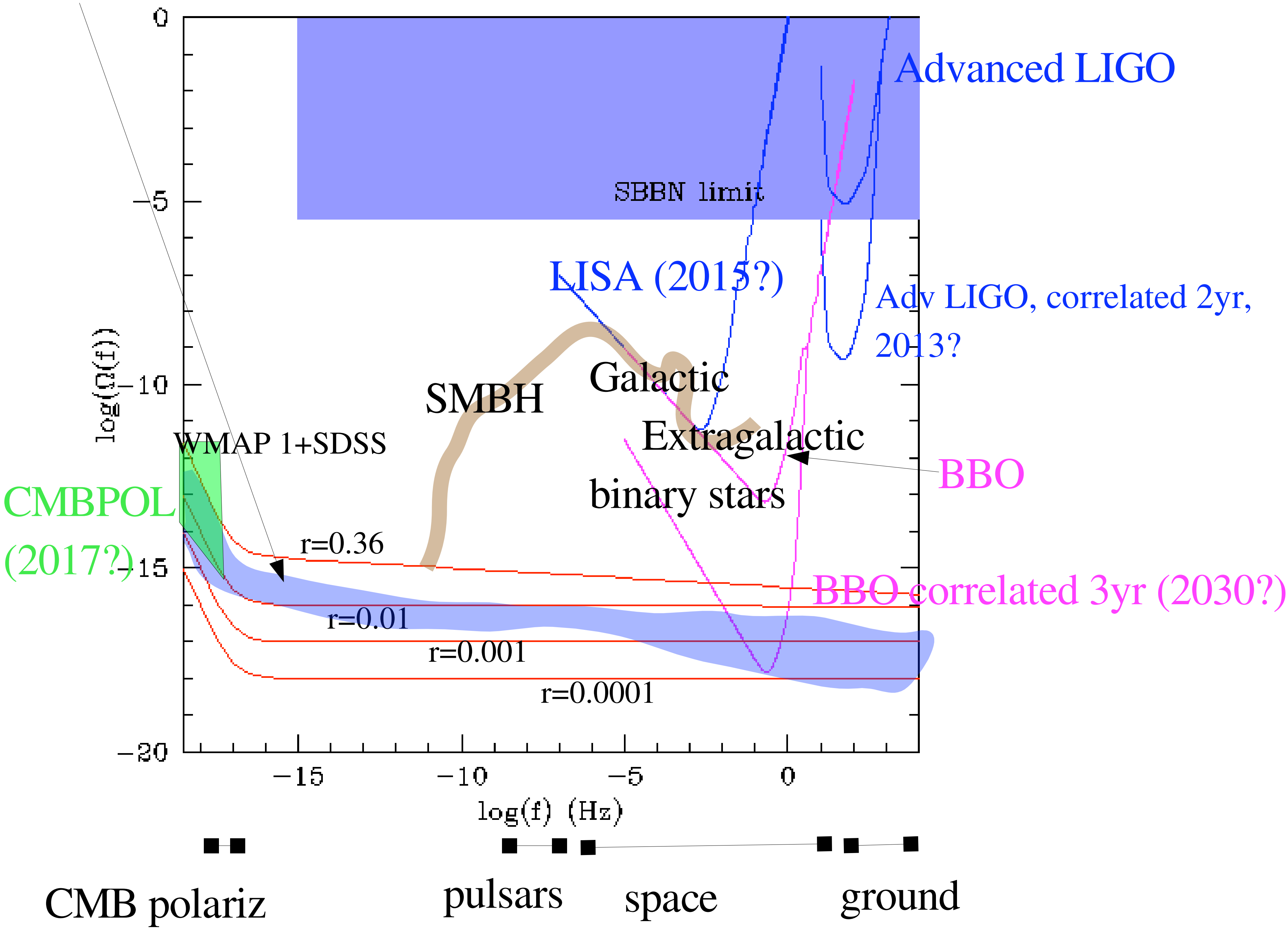
Emphasis: LISA's unique role

1) Precision measurement of (fairly) simple systems that are theoretically tractable. LISA measures interesting parameters and sources that are inaccessible to electromagnetic measurements.

2) Astronomers' greatest interest is in sources for which there are also electromagnetic diagnostics, so both sets of measurements can supply information on interdependent aspects of sources that cannot be obtained with GW or EM measurement alone.

3) Discovery space: the known unknowns and the unknown unknowns. Possibly the greatest impact...

Predictions of least contrived scale-free inflation models



S. Phinney -LISA Symp 6, 18 June 2006